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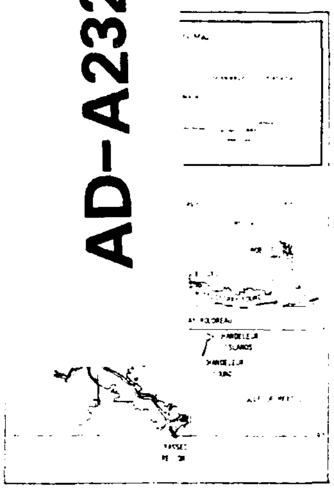

HYDRAULICS LABORATORY

TECHNICAL REPORT HL-91-2

TABS-MD NUMERICAL MODELING INVESTIGATION OF SHOALING IN THE MISSISSIPPI RIVER-GULF OUTLET

by

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The combined effects of subsidence and erosion have caused encroachment of Lake Borgne toward the Mississippi River-Gulf Outlet (MR-GO) canal. The shoreline erosion poses the potential to alter the general circulation patterns in the area and increase the channel maintenance requirements in MR-GO. A numerical model was developed for the simulation of hydrodynamics and sediment transport to evaluate the potential changes in sedimentation. The numerical model was verified to hydrodynamics for three separate events, each with considerable degree of meteorological contamination. The sediment transport verification to the observed suspended sediment concentrations and the channel shoaling rates was initiated. The final sediment transport verification was not achieved as the project was terminated due to revised costs associated with the proposed bank line protection construction. This report documents the work performed toward the original study objectives.

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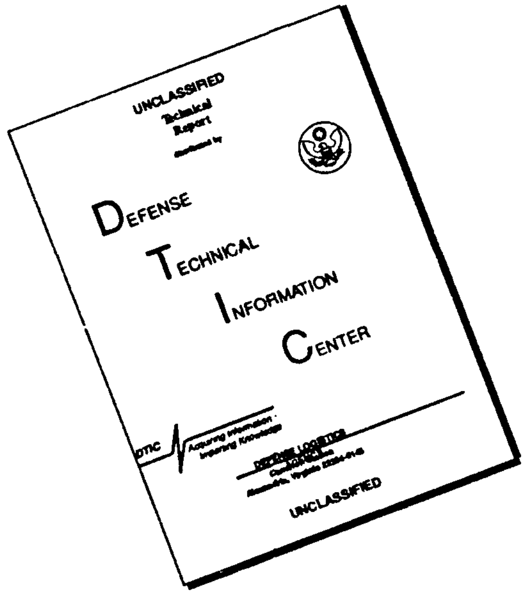

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PREFACE

The Mississippi River-Gulf Outlet numerical modeling described in this report was performed for the US Army Engineer District, New Orleans (CELMN), Planning Division, as part of a Life Cycle Management Study.

Messrs. Cecil Soileau and Jay Combe were CELMN Engineering Division liaison during the study.

This study was conducted in the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) during the period of October 1988 to September 1989 under the general supervision of Messrs. Frank A. Herrmann, Jr., Chief, HL; Richard A. Sager, Assistant Chief, HL; William H. McAnally, Jr., Chief, Estuaries Division (ED), HL; and Joseph V. Letter, Jr., Chief of the Estuarine Simulation Branch (ESB), ED.

The HL work was performed by Ms. Barbara P. Donnell and Messrs. Larry M. Hauck and Gary C. Lynch, all of ESB, under the technical guidance of Mr. Letter. Additional modeling support was provided by Dr. Tyrus McCarty, University of Mississippi, Oxford, MS, working with ESB under the Intergovernmental Personnel Agreement. Ms. Melinda Wooley and Mr. Mark Bardwell, ED, served as numerical modeling assistants during the project.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
miles (US nautical)	1.852	kilometers
miles (US statute)	1.609347	kilometers
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square feet	0.09290304	square meters
tons (2,000 pounds, mass)	95.76052	kilopascals

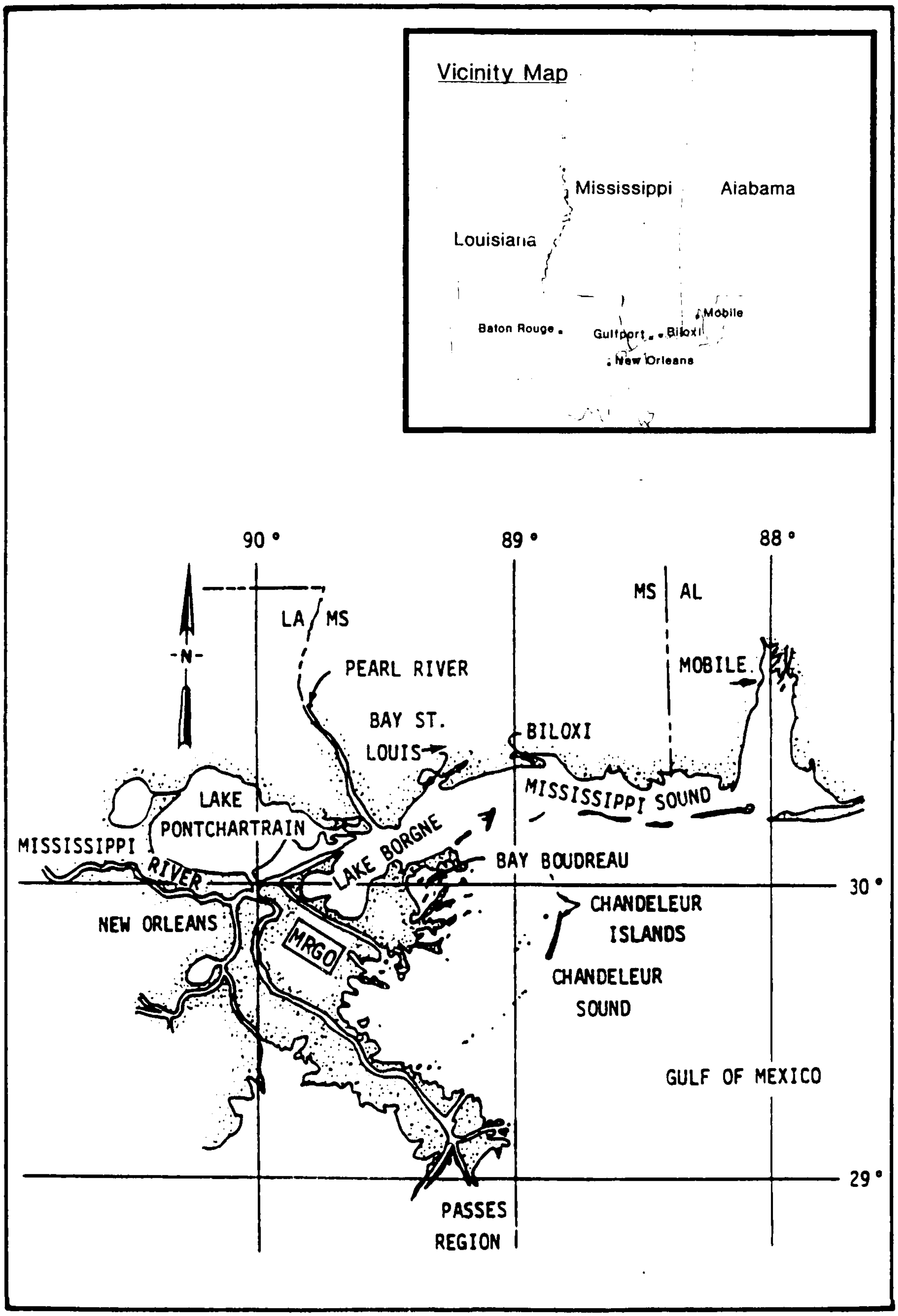


Figure 1. MR-GO study area

TABS-MD NUMERICAL MODELING INVESTIGATION OF SHOALING IN THE MISSISSIPPI RIVER-GULF OUTLET

PART I: INTRODUCTION

1. This report describes work performed in numerically modeling the Mississippi River Gulf Outlet in southern Louisiana. The work was performed by the Waterways Experiment Station Hydraulics Laboratory for the U.S. Army Engineer District, New Orleans (CELMN).

Background

2. The Mississippi River Gulf Outlet (MR-GO), Figure 1, was completed in 1968 to provide a 40-mile shortcut from New Orleans to the Gulf of Mexico for ship and barge traffic. The MR-GO is a 76-mile-long man-made waterway that extends from the city of New Orleans to the Gulf of Mexico. It includes a 36-ft-deep land cut through 43 miles of marsh and shallow water areas. Wave wash and drawdown from ships transiting the MR-GO have eroded the bankline and altered the original channel width from 650 to 1500 ft.

3. Bank erosion adjacent to the MR-GO is responsible for the loss of 4,200 acres of highly productive marsh lands in the past 20 years. The two primary channel gaps, shown in Figure 2, cut through the marshy land separating the MR-GO canal from Lake Borgne. The gaps, designated as Shell Beach and Martello Castle, are in danger of widening to over 4000 ft from their present width of approximately 100 and 200 ft, respectively.

4. Where the MR-GO traverses marsh areas (miles 23 to 60), the average shoaling rate is approximately 40,000 cubic yards per mile per year. Previous studies (Howard et al. 1984) have estimated that bank erosion accounts for as much as 55% of the shoaling material in the canal. Other sources of shoal material may be (1) sediment carried into the canal from Breton Sound on flood tide, (2) material tidally transported into the canal from Lake Borgne, and (3) sediment brought to the canal from the interior marshes. Currently banks of the non-leveed reaches are retreating at rates varying from 5 to over 40 ft per year. The average rate of bank retreat is about 15 ft per year for the northern unprotected bank. Potential consequences of a wider gap or breach are: increased sediment from Lake Borgne may be swept into the channel

Figure 2. MR-GO channel interchange with Lake Borgne. Two primary gaps are shown as the Shell Beach Gap and the Martello Castle Gap

by tidal action; developed areas to the southwest would be exposed to direct hurricane surge attacks from Lake Borgne; the rich marsh habitat around the area would be converted to open water; and the marsh would be exposed to higher salinity concentrations. Without corrective action, the breached bank area may become a major channel maintenance problem. Prior to the onset of this study, it was estimated that the widened gaps would increase dredging maintenance cost six-fold by year 2002 and exhaust the dredged material disposal area located on the MR-GO south bank between miles 23 and 27 by year 2017.

5. The New Orleans District requested assistance by the US Army Engineer Waterways Experiment Station (USAEWES) in determining the effects of widened gaps between Lake Borgne and the MR-GO channel. Preliminary work had been conducted by the New Orleans District concerning bank protection along the MR-GO channel, in particular at the Shell Beach and the Martello Castle Gaps (Figure 2). Beginning in September of 1988 the New Orleans District funded a 3-part data collection effort within the MR-GO system (Fagerburg 1990) and a multi-faceted numerical modeling approach to study both the hydrodynamics and sediment transport of the area.

Objectives

6. The objective of this numerical modeling study was to determine the expected rates of shoaling in MR-GO channel when the Shell Beach and Martello Castle gaps between Lake Borgne and the outlet were each widened to a maximum of 5000 ft. One of the primary tasks required to meet that objective is to adequately describe the circulation patterns in the system. The purpose of this report is to describe and summarize the activities involved in the development of the models used in this study and to document potential areas of improving future modeling efforts in marsh environments.

Approach

7. An environment subjected to extensive bank erosion such as the MR-GO poses a particular modeling challenge. There is presently no numerical modeling capability to simulate the actual process of bankline erosion, with undercutting, sloughing and slope adjustment. However, the TABS-MD (TABS

Multi-Dimensional) numerical models provide the ability to simulate the impact of an assumed bankline erosion rate, and appropriate supply of sediment to the canal resulting from that erosion. Furthermore, insight into future sedimentation can be obtained from comparing model results for the existing channel/gap configuration with that of a projected bathymetric condition with widened gaps.

8. To accomplish the objectives of the study, a numerical model was constructed using the TABS-MD numerical modeling system for hydrodynamic (RMA-2V/RMA-10) and sediment transport (STUDH/SED-8). The MR-GO numerical modeling approach consisted of the following interrelated parts:

a. A large-scale or comprehensive numerical model of the MR-GO and neighboring waters was developed to simulate the hydrodynamic and sediment transport characteristics of the area.

b. Synoptic field data were obtained to verify the numerical model. A field data collection program for MR-GO provided verification data and was supplemented by previous data collection efforts in The Biloxi Marshes and Lake Pontchartrain.

c. Wind data were acquired from the New Orleans Airport, the Chandeleur Island Gage operated by the National Oceanographic Data Center, and field survey observations to provide necessary input for the numerical models.

d. The previously developed large scale WIFM Mississippi Sound finite difference numerical model (W-MSM) was used to provide water-surface elevations within the Sound which in turn were used to determine tidal boundary conditions for RMA-2, the two dimensional (2D) depth averaged hydrodynamic finite element (FE) model.

e. The RMA-2 model was used to define the general circulation pattern and hydrodynamics within the study area. These hydrodynamic results were used to drive the 2D sediment model.

f. The 2D sediment transport model STUDH was used to simulate cohesive sediment concentrations over a tidal cycle and to compare yearly dredging volumes of a worst-case breached MR-GO channel to existing conditions.

g. The three dimensional (3D) FE numerical models RMA-10 and SED-8 were needed to investigate salinity induced velocity and sedimentation affects. Necessary boundary conditions were obtained from the RMA-2 and STUDH 2D models.

PART II: DESCRIPTION OF THE MODELS

Modeling Overview and Procedures

9. To calculate transport of cohesive sediment materials, hydrodynamic data are needed at many locations in the flow field. Therefore, the first steps in sediment modeling was the development of the time varying circulation patterns. The models selected were WIFM-Global Grid Model of Mississippi Sound, RMA-2 (Two-Dimensional Model for Open-Channel Flows), STUDH (Sediment Transport Unsteady Two-Dimensional Flows, Horizontal Plane), RMA-10 (Multi-dimensional hydrodynamic and density coupled model), and SED-8 (Multi-dimensional sediment transport model). The RMA-2V and STUDH are depth averaged finite element models which are included in the TABS-MD modeling system supported by the US Army Corps of Engineers. RMA-10 and SED-8 are one-, two-, and/or three-dimensional finite element models which will soon be incorporated into the TABS-MD system.

WIFM - Global Grid Model of Mississippi Sound

10. The Global Grid Model of Mississippi Sound was developed at USAEWES in the early 1980's (Schmalz 1985) for use with the WIFM finite difference model (W-MSM). The Global Grid Model of Mississippi Sound contains 6,612 finite difference cells (114 x 58) and covers the geographic area indicated in Figure 3. The gulf boundary for the Mississippi River Gulf Outlet TABS-MD model mesh is also indicated in Figure 3. Water-surface elevations were calculated every six minutes for each tidal cycle simulation. The background and verification for W-MSM is described by Raney and Doughty (1989).

Computational Finite Element Mesh

11. The MR-GO two-dimensional computational mesh was used for both the RMA-2 and the STUDH numerical models. Figure 4 shows the 5441 nodes, 1734 element computational mesh. The mesh encompasses the area from Mississippi Sound at Pascagoula Bay, to Mississippi River Delta in Breton Sound, and from Lake Pontchartrain to the Gulf of Mexico beyond Chandeleur Sound. The mesh has detailed resolution within Lake Borgne and the MR-GO, expands to medium

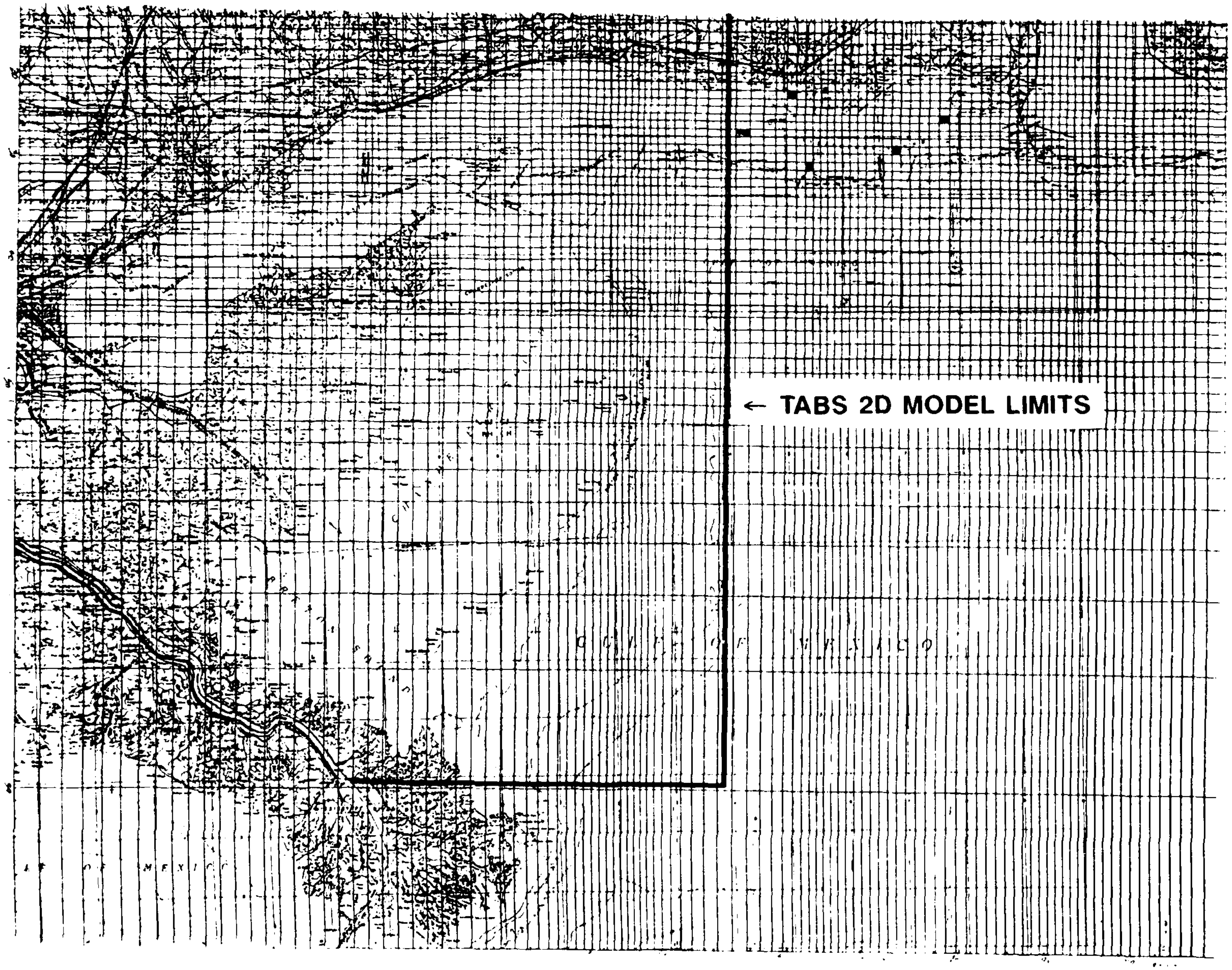


Figure 3. WIFM 'lississippi Sound finite difference model

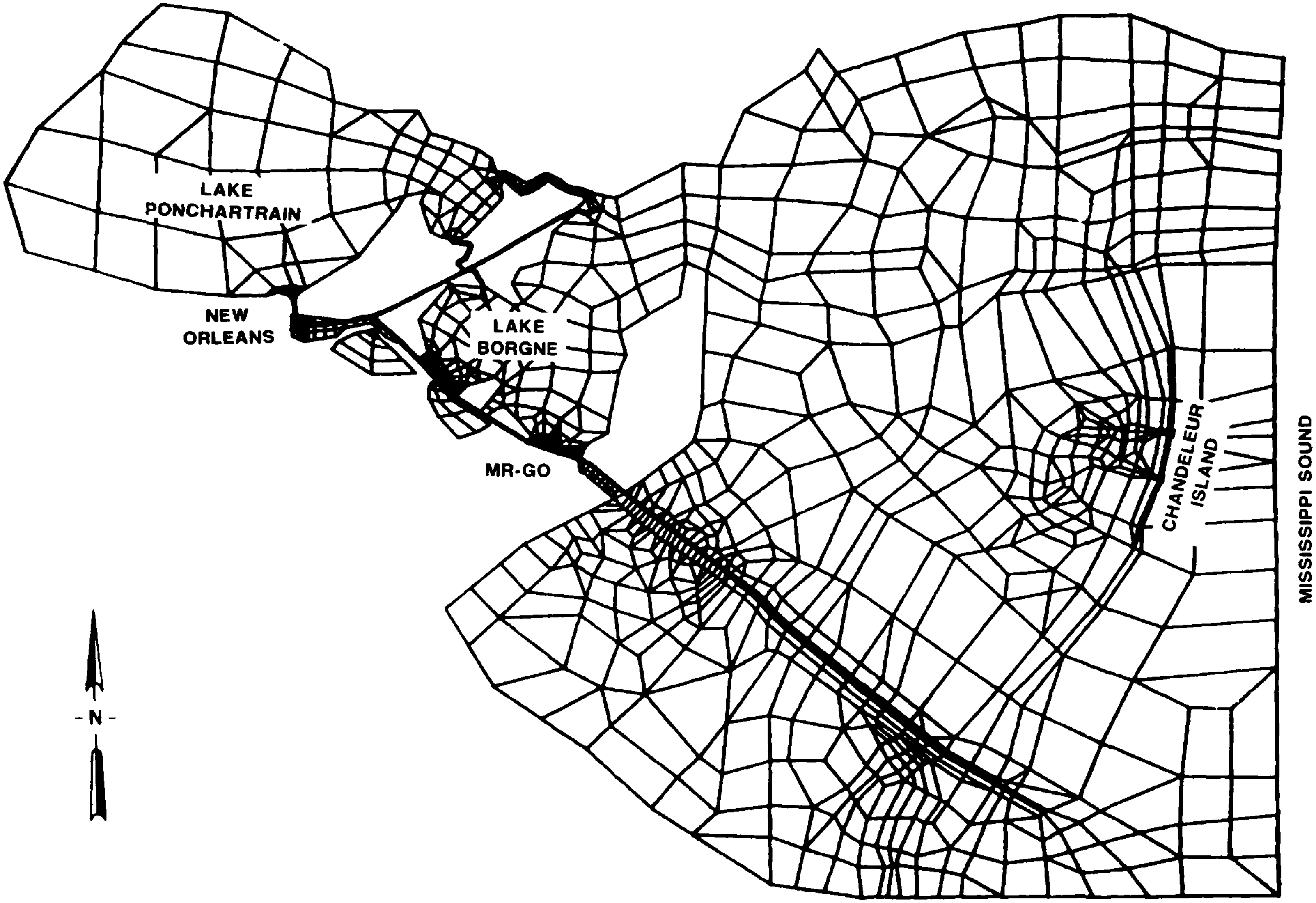


Figure 4. TABS MR-GO two-dimensional computational mesh

resolution within the Sound and then expands to course resolution toward the outer boundary. Although the mesh encompasses a large domain, this schematization greatly simplifies the boundary conditions and adequately defines the total tidal prism of the system. The eastern boundary extended to 30 degrees 25 minutes longitude. Tidal boundary conditions were applied on the southern and eastern borders. The MR-GO primary study area shown in Figure 2 indicates the primary interchanges between Lake Borgne and the channel as they existed in 1988.

12. Most of the general bathymetric data input to the model were derived from the following 1:80,000 National Ocean Survey charts:

Chart No.	Location	Date
11363	Chandeleur and Breton Sounds	1985
11364	Mississippi River: Venice to New Orleans	1989
11369	Lake Pontchartrain	1983
11371	Lake Borgne to Cat Island	1984

However, a December 1988 hydrographic survey provided the necessary information to describe the width and cross-section along the five-element wide MR-GO channel. Plates 1 through 4 summarize the MR-GO channel hydrographic survey by distinguishing the parameters according to left, middle and right side of the channel. A break point depth of 8 ft was used to determine the middle section. Note that the left bank generally references the western side. The MR-GO hydrographic survey station locations are identified in Plates 5 and 6. Note that the Martello Castle gap is synonymously named Bayou Dupre and the Shell Beach gap is designated as Bayou Yscloskey. Aerial photography helped to identify major and minor interchanges between the MR-GO channel and Lake Borgne. The USAEWES field data collection program also provided necessary bathymetric information for the two primary gaps.

RMA-2 Hydrodynamic Model

13. RMA-2 is a time dependent, non-linear, two-dimensional (2D) horizontal model for open-channel hydrodynamics. The model solves the depth integrated x- and y-momentum equations along with the continuity equation (Reynolds form of Navier-Stokes equations). An eddy-viscosity formulation

accounts for turbulent exchanges. Other terms in the momentum equation include bottom friction, Coriolis effect, and surface wind stress. Bed friction is calculated with Manning's equation. The program allows for the turbulent exchange coefficient to be specified in a local coordinate system for each element. This permits an exchange coefficient for directions parallel to and perpendicular to the predominant direction of flow. The model recognizes computationally wet or dry elements and corrects the mesh accordingly. Since the MR-GO study area is surrounded by extensive marsh zones, the marsh porosity option within RMA-2 (version 4.2) was used to represent the bottom as an irregular surface and to adjust the effective width of the element as the water level fluctuated. This concept is basically analogous to porosity in ground water modeling. There are five basic specifications which may be applied at each node: no boundary condition, flow boundary condition, parallel flow boundary condition (i.e., slip flow), stagnation boundary condition (zero flow), and time varying water-level boundary condition. In this application, water levels were extracted from the Mississippi Sound model and applied as boundary conditions to the southern and eastern edges of the MR-GO mesh. All other boundary nodes received a parallel flow (i.e., slip flow) boundary condition.

14. A one-hour time-step was used for the RMA-2 hydrodynamic model. This time-step increment had proven itself adequate in previous numerical model applications within the Louisiana marsh environment. Each tidal cycle simulation consisted of a 36-hour spin-up period, and a 25-hour prototype simulation.

15. Results from RMA-2 consist of water depths and current velocities at each computational point. However, water levels, velocities, and discharge results can be displayed at any location within the area modeled based on the solution being continuous in space. The forms of output consist of printed tables, time-history plots for a given location, contour plots, factor maps, and velocity vector plots.

STUDH Sediment Transport Model

16. STUDH is a two-dimensional vertically integrated horizontal sediment transport model in the TABS-MD system. The model has the capability of addressing either cohesive (clay) or noncohesive (sand) sedimentation. The

model solves the 2D convection-diffusion equation with bed source/sink term. A structured bed layering with consolidation can be specified. STUDH uses the same computational mesh as RMA-2 to define the geometry. It requires the velocity field results from RMA-2 as input. Typically the model is run for multiple tidal cycles to establish a representative bed layer and concentration field, then actual tidal cycle simulations are conducted. The STUDH model was modified for this study to incorporate wind fetch lengths by computational node for any wind direction of a 16-point compass. This allowed the calculation of wind-wave induced bed shear at any point in the mesh for a given wind direction. This revision was an important factor for the MR-GO area which frequently has wind dominant behavior.

17. STUDH output at each time-step consists of sediment concentrations, bed shear stress and cumulative bed change for each computational point in the mesh.

RMA-10 Multidimensional Model for Density-Stratified Flows

18. The RMA-10 model was designed as an extension of the well-proven RMA-2 hydrodynamic model of the TABS-MD system. The model solves the Reynolds form of the three-dimensional (3D) Navier-Stokes equations, the mass continuity equation, a transport equation (for salt and temperature), and uses an equation of state to relate the density to the salt concentration and the temperature. The hydrostatic assumption is made by assuming that vertical acceleration can be neglected. The continuity equation is integrated over the vertical dimension and used to solve for water depth. The local continuity equations are later used to solve for the local vertical velocity at each node, with appropriate surface and bottom boundary conditions relating vertical velocities to the horizontal velocities and the water surface.

19. The formulation of the RMA-10 model closely parallels that used in RMA-2. This provides the capability of coupling a section of 3D resolution to a 2D horizontal section with the proper selection of transfer conditions in the region where the sections join. This philosophy was later extended to additionally include one-dimensional elements and 2D laterally averaged elements. The present model supports any combination of these formulations, with appropriate limitations in the transition zones. This multidimensional approach allows the modeler to focus the computer resources in the areas where

resolution is truly required and fit the formulation to match the solution requirements by zone of mixing characteristics. Figure 5 shows the multidimensional MR-GO inset mesh used for the RMA-10 simulations.

20. RMA-10 output is similar to that of RMA-2 with additional parameters of vertical velocity and salinity concentrations.

SED-8 Multidimensional Model for Sediment Transport

21. The sediment transport model (SED-8) is a companion model to the multidimensional hydrodynamic model (RMA-10), with a parallel finite element formulation (Ariathurai, 1982) which uses the same geometric discretization and is driven by the hydrodynamics from RMA-10. The model solves the three-dimensional convection-diffusion equation with bed exchange based on empirical relationships developed from laboratory and field experimentation. The model is designed to handle either cohesive or noncohesive sediments. For noncohesive sediments the bed interaction is by means of a bedload computation, and for the cohesive materials it is by means of a relationship between shear stress and rate of deposition or erosion. For deposition, the fall velocity is used in establishing the bed flux.

22. In stratified waters there is an obvious advantage in using the RMA-10/SED-8 models over the RMA-2/STUDH models. Density-driven velocities cannot be modeled accurately with a two-dimensional depth averaged model.

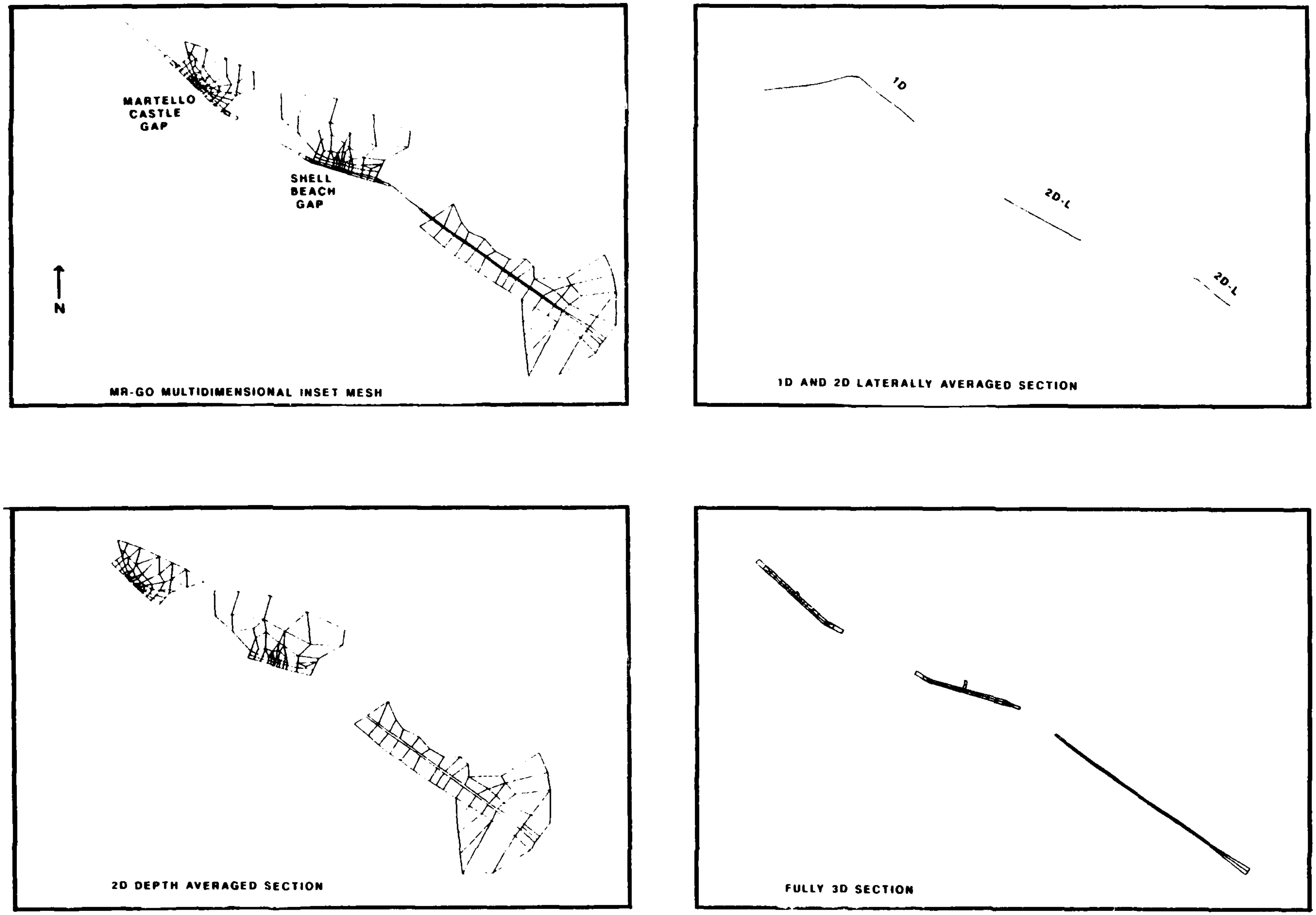


Figure 5. TABS multidimensional MR-GO inset mesh

PART III: VERIFICATION PROCESS

Available Field Data for Verification

23. The data collection procedures conducted for the MR-GO project are presented in Fagerburg (1990). In summary there were six continuous water level recorders, three velocity range locations each with multiple stations, and two continuous automatic water sampling recorders. Figures 6 and 7 show the locations of each of the USAEWES water level, velocity, and water sample locations used to verify the numerical models. The water level recorders were on site from 4 Oct 88 to 28 Nov 88 and saved the data on cartridges every 15 minutes. The automatic water sampling recorders were on site at the two primary gaps from 25 Oct 88 to 28 Nov 88 and collected the water in bottles every 6.25 hrs between surveys, and every 0.5 hrs during the surveys. Three 8-hour surveys were chosen to represent different environmental conditions and to coincide with LANDSAT overflights of the area. The surveys were conducted from approximately 0730 to 1600 CST and are listed below:

Verification Prototype Survey Events

Survey	Date	Wind Condition
V-1	10-26-88	3-16 mph wind from SE
V-2	11-11-88	3-22 mph wind from N/SE
V-3	11-27-88	2-18 mph wind from S/NW

Note that a significant frontal passage was observed for both the V-2 and V-3 November surveys. Surface analysis weather maps were obtained from the US Department of Commerce for the three survey dates and are provided in Plates 7 through 9.

24. Suspended sediment concentrations were determined from water samples collected at each of the three MR-GO ranges during the survey periods. As possible with any tasks dependent on the weather, extensive cloud cover prevented LANDSAT imagery of the study area on all three surveys. Hence the available data for suspended sediment verification was limited to discrete sampling data. The intent was to analyze the LANDSAT image to define surface sediment characteristics and compare them with the near surface suspended sediment data collected during the surveys. Areas which favorably compared to

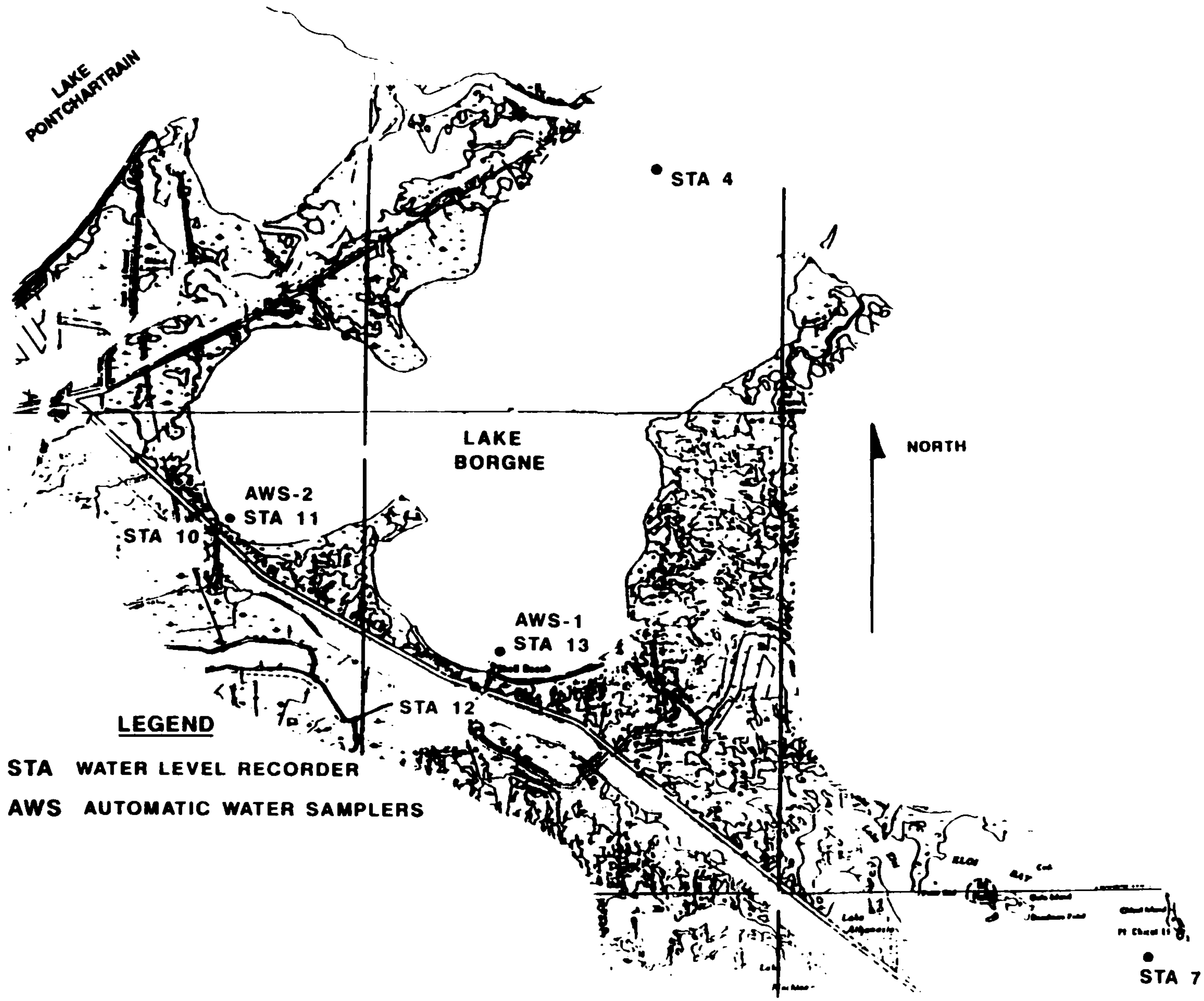


Figure 6. WES field data water level and water sample station locations

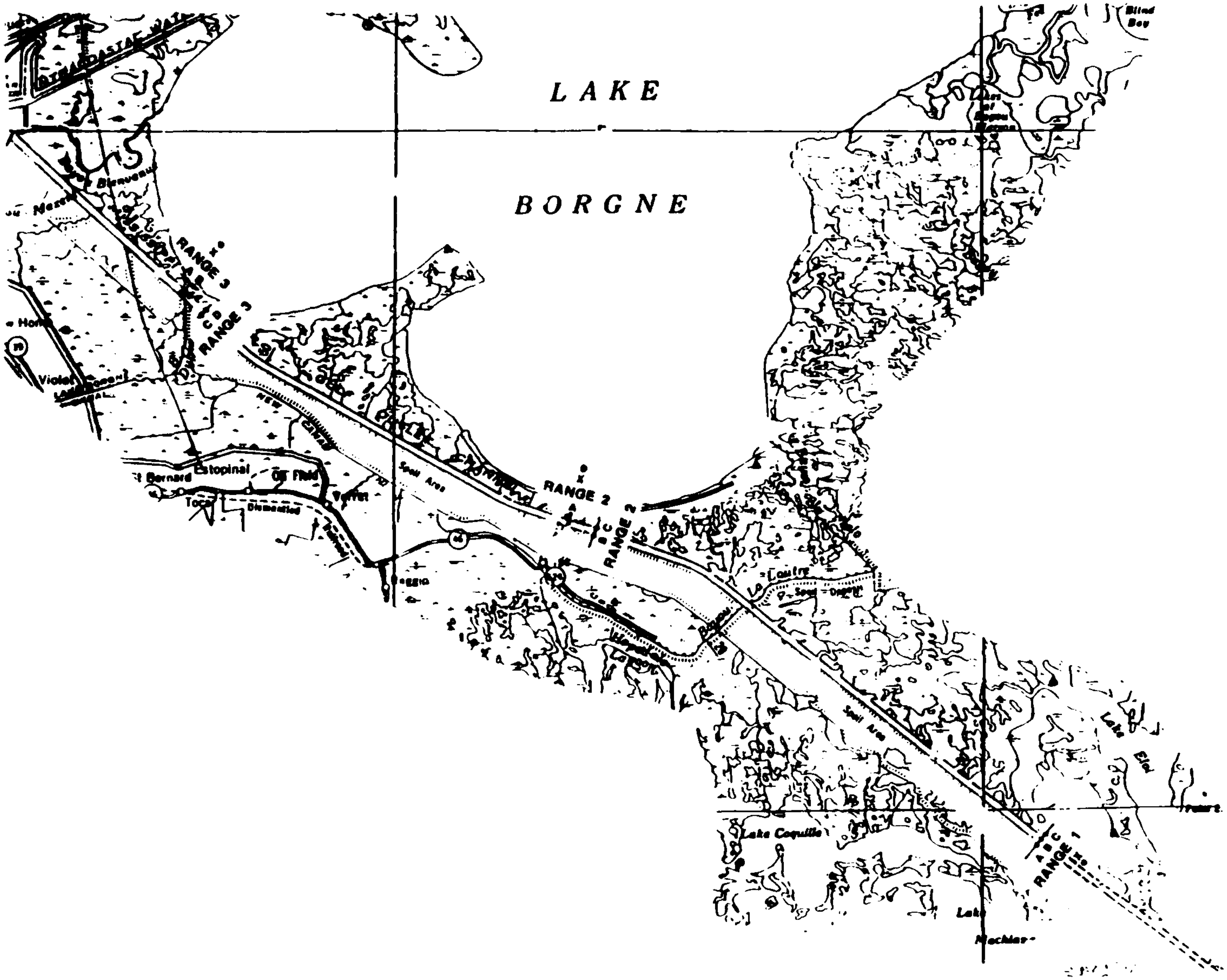


Figure 7. WES field survey range station locations

the ground truth data could be interpreted to have like concentration values Using this approach (described in Xiusheng 1987), two or three prototype stations could have been expanded to provide suspended sediment data over the entire geographical area within the LANDSAT image.

25. Prior to this study, there had been an extensive prototype acquisition conducted by USAEWES in the Lake Pontchartrain vicinity during the late 1970's which provided tidal harmonic constituents and phase relationships within the open waters. These data are described in Outlaw (1982). In addition there was a 1986 data collection effort conducted by CEWES in the neighboring Biloxi Marshes as described in Pankow et al. (1989). These data provided general tidal phase relationships and circulation trends.

WIFM Global Mississippi Sound Model Verification

26. Verification procedures for the W-MSM are described in Raney and Doughty (1988).

27. W-MSM was verified for the MR-GO area using the three verification sets listed above. Prototype water surface elevation data collected at four locations, (sta 4, 7, 11, and 13) were used to ensure that the model was accurately reproducing tidal propagation within the general MR-GO study area. Note that sta 10 and sta 12 within the MR-GO channel proper could not be included with the limited resolution of this model. The W-MSM was run for each of the three specified sets of conditions of tide, wind and river inflows. Wind data were available at three hour increments from the National Weather Service New Orleans Airport station with additional in-boat recordings by the USAEWES crew during the survey periods. A time varying (but not spatially varying) wind field was specified in the model. River inflow information was obtained from the US Department of the Interior, Geological Survey for these rivers: Tombigbee, Biloxi at Wortham, Wolf Near Landon, Alabama, Escatawpa, Pascagoula at Merrill, Black Creek at Wiggins, Pearl at Bogalusa, Boguechitto, and the Mobile.

28. The W-MSM was run for a total of 48 hours which included 12 hours of spin-up time to allow the model to pass any initial transient behavior. The final 36 hours were provided on magnetic media to USAEWES. Bottom elevation, velocity and water level results were provided at six minute intervals to

serve as boundary conditions for the MR-GO hydrodynamic numerical model, RMA-2.

RMA-2 Hydrodynamic Verification

29. Years of experience have taught us that a successful hydrodynamic verification is highly dependent on adequate geometry representation and boundary conditions. Modeling an estuary with a major marsh environment is non-trivial because it is very difficult to determine the prototype elevation of the marsh and the degree of conveyance into and through the marsh. Survey data do not exist and the modeler must rely upon aerial photography and site visits to estimate the exchange across the marsh. Verification of the RMA-2 model consisted of several test runs to adjust the marsh interactions, boundary conditions and internal coefficients so that the numerical model would reproduce water-surface elevation and current velocities measured during the three survey periods.

Tidal boundary conditions

30. In many numerical model studies water level recording field stations are located near the model boundaries to define the driving tidal forces for a model with extensive open water boundaries such as the MR-GO model. However, for this system a water level recorder in the offshore Gulf would have been very costly to install and maintain. The most cost effective technique to define the driving tidal signal was to use the existing W-MSM to supply the boundary conditions for RMA-2 rather than collect extensive water level prototype data in the offshore area.

31. A program named BMISRMA was specially designed to perform the task of extracting hourly water surface elevations and wind data from an assigned cell of W-MSM and assigning the value to the TABS-MD computational boundary node. Each of the 76 nodes along the southern and eastern-most open water boundaries of the TABS-MD computational mesh required a time-varying water level specification. The 36 available hours of water levels obtained from W-MSM were expanded another 25 hours to provide sufficient spin-up time for the RMA-2 model. The expanded boundary conditions consisted of starting the RMA-2 boundary file with a duplication of the extracted W-MSM water levels for hours 12 through 36 and hand smoothing the point of closure. This provided

sufficient time for the Lake Pontchartrain section of the RMA-2 modeling domain to acquire spin-up.

32. After the TABS-MD computational mesh had undergone dynamic flow tests to ensure the integrity of the network, each of the three sets of boundary conditions were used in 61 hour hydrodynamic simulations. The raw boundary condition data extracted from W-MSM did not result in adequate agreement with the two open water control prototype tide stations 4 and 7. Each of the three verification sets required individual time-varying adjustments from -0.4 to +0.4 ft to be made during the entire simulation. With future production work upcoming, it was considered necessary to take a conservative approach and apply an average of all the adjustments. This averaging technique would permit a logical approach toward adjusting boundary conditions when prototype water level data would not be available.

Model coefficients

33. Once the boundary condition average adjustment approach had been adopted, progressive adjustments were made in the Manning's n value roughness parameters, eddy viscosity coefficients, and marsh porosity factors to verify RMA-2 predicted water levels and velocities to prototype data. The marsh porosity factors are described in the TABS System documentation (USAEWES 1990). The factors include the bottom elevation offset (AC1), transition range of the distribution (AC2), minimum surface width factor (AC3), and the optional override bottom elevation (AC4, not used). Adjustments were made through repeated applications of RMA-2 until one set of coefficients performed equally well for all three verification data sets. Table 1 describes the coefficients for RMA-2.

Results

34. RMA-2 results compared to observed field data for each of the three survey periods are shown in Plates 10 through 15. Prototype data stations were previously identified in Figures 6 and 7. All water level stations are provided but only the velocity stations for the center of the channel and gaps are provided. For realistic comparability to the RMA-2 model, the velocity field data were depth integrated. Plates 16 and 17 show plotted head differences across the gap (MR-GO channel station minus Lake Borgne station) versus velocity within the gap. A positive value for velocity indicates that the flow is into Lake Borgne.

35. In general the tidal verification was adequate despite the

RMA-2 Hydrodynamic Coefficients

Location	Manning's n-value	Eddy Viscosity lb-sec/sq ft	Marsh Porosity Parameters AC1 ft	AC2 ft	AC3
Pontchartrain	.015	350	n/a		
Rigoletts	.020	250	n/a		
Lake Borgne mud	.015	350	n/a		
Lake Borgne shell	.020	250	n/a		
MR-GO Channel	.010	150	n/a		
Disposal Area	.025	250	no flow		
High Marsh	.040	250	6.0	1.0	.05
Low Marsh	.028	250	6.0	6.0	.25
S.E. Corner	.022	1500	n/a		
Transition Gulf	.018	700	n/a		
Deep Gulf	.015	350	n/a		
Gulf	.018	250	n/a		
Shallow Gulf	.020	500	6.0	1.0	.05
Island	.030	250	no flow		
Chandeleur Sound	.030	250	n/a		
Shell Beach Area	.022	250	6.0	.5	.018
Martello Castle	.030	250	6.0	1.0	.05
Gap Range #2	.030	250	n/a		
Gap Range #3	.020	250	n/a		
Intracoastal	.020	250	n/a		
Seabrook Area	.020	250	n/a		
Tidal Storage	.050	150	6.0	10.0	.2

noticeable wind effects in the two November surveys. However, there were several deficiencies associated with the hydrodynamic verification. These included a tendency for excessive damping of the tide up the MR-GO channel, a multi-hour phase discrepancy in the model versus prototype velocities within the two primary gaps, and a low velocity magnitude trend within the MR-GO channel proper. The concerns over the velocities prevented USAEWES from concluding that the MR-GO hydrodynamic model was verified, particularly since the primary objective of the study involved the use of velocities in sedimentation predictions. Because of time constraints and a major change in supercomputer systems, it was not feasible to achieve an accurate hydrodynamic verification.

STUDH Sedimentation Verification

36. STUDH, the 2D depth integrated sediment transport model, relies on the RMA-2 model to provide the hydrodynamic results at each time step. In

short, if the hydrodynamics are correct, and the basic parameters are within the range of reasonableness, the initial verification steps involve tuning the model sediment concentration predictions with field data.

37. Very little time was devoted to the MR-GO sediment verification. The sediment transport aspects of the study were felt to be academic in that we knew that the hydrodynamics driving the sediment model were not adequately verified. However, the sediment model was needed to be poised and ready in the event of a breakthrough with the hydrodynamic verification. Suspicions were that wind was the primary obstacle associated with hydrodynamic verification, in which case some preliminary insights could be gained from the sediment model in a comparative sense. The following description of the sediment transport aspects of this study should be viewed as highly preliminary in that the proposed rigorous sediment transport verification was not conducted.

38. The sediment transport verification procedures were to include an adjustment of the model to replicate both suspended sediment concentrations at the field monitoring stations and analysis of LANDSAT spectral data correlations using those suspended concentrations. The LANDSAT data were not usable, however, because of extensive cloud cover on all three of the field exercises. In addition, a comparison of channel shoaling rates with historical dredging records was part of the verification approach.

39. The sedimentation problems within the system are complicated by shoreline erosion. The historical shoreline recession is the result of actual bankline sediment erosion and subsidence. The precise contribution of each process to the shoreline recession is unclear, but CELMN has made an estimate which was used to prescribe the sediment supply to the channel due to the shoreline erosion. The verification included sensitivity testing of the model with various levels of erosion mass loadings to provide guidance as to whether the shoaling process within the MRGO channel is supply limited or process limited. This information is useful for the verification effort, giving guidance to further model adjustments. Once the model is verified, the sensitivity can then be of value in understanding the field processes.

Concentration boundary conditions

40. The gulf boundary nodes were assigned 50.0 parts per million sediment concentration as a boundary condition for STUDH. This value was chosen in a general attempt to match sediment concentrations values at the Gulf-most

suspended sediment prototype measurements, Range 1: sta 1A, 1B, 1C, and 1X as indicated previously in Figure 7.

Model coefficients

41. The primary parameters for STUDH were selected based upon previous numerical modeling sedimentation work in the vicinity. The settling velocity for the cohesive sediments was assigned 0.00005 m/sec based upon extensive Atchafalaya Bay analysis done in the 1980's. Other parameters for STUDH were 0.150 n/sq m for critical shear stress for deposition and 0.20 n/sq m for critical shear stress for particle erosion. Four cohesive consolidating layers were assigned as follows:

Parameters Defining Cohesive Bed Layers

Layer Number	Thickness (m)	Critical Shear Stresses for Erosion (N/sq m) Particles	Mass	Erosion Constant (kg/sq m-sec)
Top 1	0.15	0.2	2.0	0.0002
Middle 2	0.15	0.4	4.0	0.0002
Middle 3	0.15	0.6	8.0	0.0002
Bottom 4	1.0	900.0	900.0	0.0002

Procedures

42. The hourly results from the partially verified RMA-2 hydrodynamic model were interpolated (spin-up time was eliminated) to 30-minute values and converted to the metric system by a TABS-MD program called ENGMET. The sediment transport model was run for half-hour time steps in a COLDSTART initialization then in HOTSTART mode. The terminology COLD- or HOTSTART indicates whether the concentration field, or bed conditions are beginning from a user input constant value or from a previously calculated value obtained by a previous model run. Several steps are necessary to initialize the cohesive bed structure and concentration field in the sediment transport model before meaningful results can be obtained from the model. A mean tide no-wind 25 hour tidal cycle run from RMA-2 was used as the hydrodynamics for the COLDSTART STUDH run to initialize the bed layer. The next STUDH run HOTSTARTED the calculated bed layers obtained from the COLDSTART and used the hydrodynamics from the verification survey periods. The HOTSTART STUDH run was composed of a tidal cycle to stabilize the bed and concentration field followed by a tidal cycle of results sufficiently removed from initialization to be aptly compared to field data. The chart below describes the process.

COLDSTART | No-Wind / Bed Layer Established | HOTSTART | With-Wind / Stabilized | With-Wind / Analysis |

Results

43. The sediment verification involved statistically combining the three verification events and the no-wind event into a typical year of channel shoaling and comparing that to historical dredging volumes within the MR-GO. The frequency weight applied to each of the four events were: 0.04, 0.03, 0.02, and 0.91 (total of 1.00) for survey periods V1, V2, V3, and a mean-tide no-wind event. The general magnitude of the frequencies applied were obtained from long-term wind data (1966-1986) from the New Orleans Moisant airport station (Ebersole 1985) and adjusted to achieve a near-match to the reported prototype value. The STUDH model calculated total shoaling from miles 25-60 of the MR-GO channel to be 1,447,000 cubic yards/year-mile as compared with the prototype value of 1,425,000. Although the statistical combination of total shoaling appeared too good to be true, the distribution of the predicted shoaling did not match historical records.

44. Since STUDH is a depth-averaged 2D model, it was limited in reproducing the distribution of shoaling on the MR-GO since the channel changes from being well-mixed near the Gulf to stratified in the upper channel. Due to the documented low hydrodynamic model velocities in the lower MR-GO channel, the sediment supply from the Gulf was low by a factor of 5, and the deficit in transport was compensated by high fluxes of material from Lake Borgne in the model compared with the field data. These factors were further aggravated by the model's suspended concentration being somewhat low. Thus the model's preliminary verification was based on a biased sediment supply and could be misleading.

Multidimensional Hydrodynamic Verification

45. The multidimensional computational mesh concentrated the modeling domain within the MR-GO channel and the two primary gaps. The multidimensional mesh (MESH10) presented earlier in Figure 5 consisted of 1D elements in the upper 7 miles of the MR-GO channel, 3D elements in the vicinity of the gaps, and 2D laterally averaged elements for transition between 2D and 3D

zones. Traditional 2D depth averaged elements were used elsewhere and were required as tidal boundary conditions.

46. The inset MESH10 was a numerical modeling challenge in that the mesh required multiple boundary conditions each of which was relatively close to the study area. Water levels were required for the gulf end of the MR-GO channel, and velocity specifications were needed at the Lake Borgne Martello Castle boundary, and at the Shell Beach boundary. The pre-verified boundary conditions which were extracted from RMA-2 for use by the RMA-10 model hindered the effort. Although several attempts were made running MESH10, it was abandoned as soon as adequate computer resources became available to allow added resolution. Another attempt at the RMA-10 verification was made by running the complete MR-GO 2D MESH, previously shown in Figure 4, with appropriate 3D layers dropped in the MR-GO channel proper. These runs were extremely computer intensive. However, this approach did not provide better results than the 2-D depth averaged RMA-2 model. The lack of adequate information to initialize the salinity concentrations both laterally and vertically prohibited the formation of density driven currents.

47. The sediment transport model, SED-8 was not attempted due to the inability to obtain verified multidimensional hydrodynamics.

PART IV: TEST OF EXISTING VERSUS PROJECTED CONDITIONS

48. Even with an unverified model, insight can be obtained by comparing results from the existing configuration with that of a projected (planned or anticipated) bathymetric configuration. Results from unverified models can be useful, provided that the results are interpreted very carefully to avoid misleading conclusions. Accordingly, the unverified models were run for existing gap widths and for the extreme projected condition of 5000-ft-wide gaps.

Procedures

49. All existing and projected condition testing followed the same basic procedures as outlined in the verification procedures. Results for the existing condition geometry with 1988 bathymetry were compared to the probable near-future worst-case MR-GO and Lake Borgne breached gaps. The projected condition had both the Shell Beach Gap at Range #2 and the Bayou Yscloskey (Martello Castle) Gap at Range #3 widened to 5000 ft with an average depth of 8 ft. The wind speed and direction for the production runs were chosen based upon the potential interchange between Lake Borgne and the MR-GO channel. The 'no-wind' run in actuality had the wind computation turned off in RMA-2 and had the wave conditions for a nominal 5 mph wind speed in the STUDH model. The nominal wind was applied in the sediment model because unusually low concentrations were occurring in the shallow marsh zones and a small degree of wind generated wave action was needed to keep the suspended concentrations within the range of values dictated by engineering judgment. In fact, boat traffic, low-speed winds, and residual wave activity agitate bottom sediments even during periods of apparent no-wind conditions. The production conditions used the 17 November 1988 measured water levels, which was a mean tide condition. The production events are described below:

Production Events

Geometry		Wind Condition	
Existing	Projected	Speed (mph)	Direction
E-1	P-1	16.5	from East-North East
E-2	P-2	16.5	from South East
E-3	P-3	5.0	from North

50. Although the computational mesh was designed to evaluate incremental widening of 1000, 2000, 3000, 4000, and 5000 ft for the two gaps, the sensitivity runs with incremental widening were not necessary due to the limited sedimentation increase in the MR-GO obtained with the projected 5000-ft gaps (worst-case).

51. The same techniques described in Part 3 were used for the production runs. In summary the sequence of events for the six productions runs involved these basic steps:

a. Run the WIFM Mississippi Sound Model (W-MSM).

b. Extract the water level boundary conditions from W-MSM and apply the average correction factor. Expand the time series to 61 hours.

c. Run the RMA-2 2D hydrodynamic model using (b) above as boundary conditions.

d. Run the STUDH 2D sediment transport model using hydrodynamics from (c) above.

e. Compare the effects of existing and projected geometry.

The hydrodynamic model was run with both existing and projected worst case geometry using the same coefficients and run time as were determined in the attempted hydrodynamic verification. The average water level correction factor, as described in Part III above, was applied to all production boundary conditions extracted from W-MSM.

Hydrodynamic Comparisons

52. Plates 18 through 29 show the effects of widening both gaps to 5000 ft. Existing versus projected conditions are plotted for each of the events. The general hydrodynamic effects of widening both gaps to 5000 ft were:

a. Slight effect on tidal phasing and increase in tidal range within the MR-GO channel.

b. A marked decrease in velocities within the gaps (sta 2A and 3A).

c. A decrease in MR-GO velocities at Range #3 (sta 3C).

d. An increase in MR-GO velocities at Range #1 and #2 (sta 1B and 2C).

The effects of wind on the water levels and velocities may be determined by comparing wind versus no-wind events. Note the wind may affect the water

levels as much as 1 ft (Plates 24 versus 28, sta 10, 11, 12, and 13), and the velocities as much as 0.9 ft/sec in the Range 3 existing condition Martello Castle Gap (Plate 25 versus 29, sta 3A).

Sedimentation Comparisons

53. The 2D sediment model did not predict a large increase in shoaling within the MR-GO channel for the worst-case widened gaps. The 25% increase in shoaling predicted with the model due to the widened gaps was considerably less than expected and instigated a thorough analysis.

54. Water and sediment flux analyses were conducted on the modeling results in an attempt to better interpret the model results. The sediment flux analysis provided the best insight into the numerical models' predictive capabilities of the depositional behavior in the MR-GO channel. Two processes appeared to cause the models' deposition in the MR-GO channel. First is the movement of material up the channel from the Gulf. Once the suspended material enters the protected waters of the marsh-lined upper channel, deposition begins and gradual reduction in both sediment concentrations and net upchannel sediment flux occurred. The limited prototype data indicated the same process.

55. The second process evident in the modeling results was a tidal pumping into the MR-GO channel from Lake Borgne. A net sediment flux into the channel occurred even when net water fluxes between the MR-GO channel and Lake Borgne approached zero. This sediment flux resulted in a local peak in deposition at the gaps between MR-GO and Lake Borgne.

56. The field data analysis suggested that the up-channel flux of sediment in the model was as much as a factor of 5 too small and that the Lake Borgne derived sediment flux was a factor of 10 too high. The implications of the improper model sediment fluxes to the MR-GO channel deposition are to distort the depositional patterns and to compromise the validity of the numerical models, in their present state of verification, to properly assess potential depositional changes from the widening of the gaps.

PART V: CONCLUSIONS

57. The numerical modeling effort of the MR-GO system was not adequately verified within the available time. This section of the report addresses the potential underlying reasons and discusses the interpreted results.

Field Data Requirements

58. One critical factor was the lack of spatially and temporally varying wind speed and direction data for the system. The RMA-2 model was operated with a spatially uniform wind field with temporal variations in wind as defined by the National Weather Service New Orleans Airport station wind data (3-hour increments). However, the RMA-2 model was capable of using both time and spatial variations if those data had been available. The hydrodynamic MR-GO model was found to be quite sensitive to wind effects, as is the prototype system. While the project was in reporting/documenting phase, additional hourly wind data located at the Chandeleur Island Buoy (National Climate Data Center Station) became available. This provided the opportunity to re-run the RMA-2 model and confirm the model sensitivities to wind (discussed in paragraph 66). Since two of the three survey periods had observed frontal passages, spatial variations in wind effects were significant. The ideal situation would have been to include a triad (acceptable) or quartet (preferred) of continuously recording wind stations (10 meters above ground), with at least one station near the primary area of interest, the gaps.

59. Data from offshore water level stations near the boundaries of the computational mesh would have been useful. As previously mentioned, using W-MSM to provide boundary conditions to the RMA-2 hydrodynamic model was in theory an economical approach; however it handicapped the modeling effort. Tidal records were needed to thoroughly determine the wind effects of the water levels on the outer boundary during the verification periods. They would have also eliminated the problems encountered from using one model's results as boundary conditions into another; any inaccurate response in W-MSM was directly incorporated into RMA-2 through the W-MSM generated boundary conditions. Reliable field data at the RMA-2 boundary would have avoided this problem. In addition, long-term tidal records could have been analyzed to determine harmonic constituents from which synthesized repetitive tidal cycles

of boundary conditions could have been generated. The closure of a repetitive tidal cycle would have been more appropriate for the sedimentation aspects of the study. However, there are inherent problems installing gages in open tidal water, and the historical rate of data return per dollar spent in such areas is not encouraging.

60. Additional intensive field measurements would have improved the verification effort. Each of the data collection periods was affected by frontal passages to varying degrees. Balancing resources between modeling and field efforts is always difficult, as is balancing use of resources between various forms of field data collection. In this case, three 8-hour surveys were used in anticipation that at least one of them would be free of cloud cover and complicating wind conditions. As it developed, none of the three data sets were unambiguous, so a larger investment in field efforts (either 25-hour-long surveys or additional 8-hour-long surveys) was needed.

61. The fact that the LANDSAT imagery could not be obtained for any of the survey periods severely hampered the sedimentation verification since large scale concentration and transport patterns could not be identified.

Computational Mesh Issues

62. During the wrap-up phase of the work, several improvements were made to the computational mesh for diagnostic testing. After detailed inspection of the conservation of mass along some of the critical areas of the mesh it was found that some areas suffered from less than desirable local conservation of mass. This led to a refinement in the level of resolution along the land boundaries to minimize local deviation in continuity caused by abrupt breaks in the boundary. Further, the tidal storage adjacent to the MR-GO channel was easily adjusted with additional resolution along the channel. Figure 8 indicates the 2D computational mesh with these revisions. This mesh was used for diagnostic sensitivity runs of the RMA-2 model.

Hydrodynamic Issues

63. The lack of long term offshore water level data near the Gulf boundary of the computational mesh has already been addressed. At a minimum, the length of the simulation for the W-MSM should have been extended to include

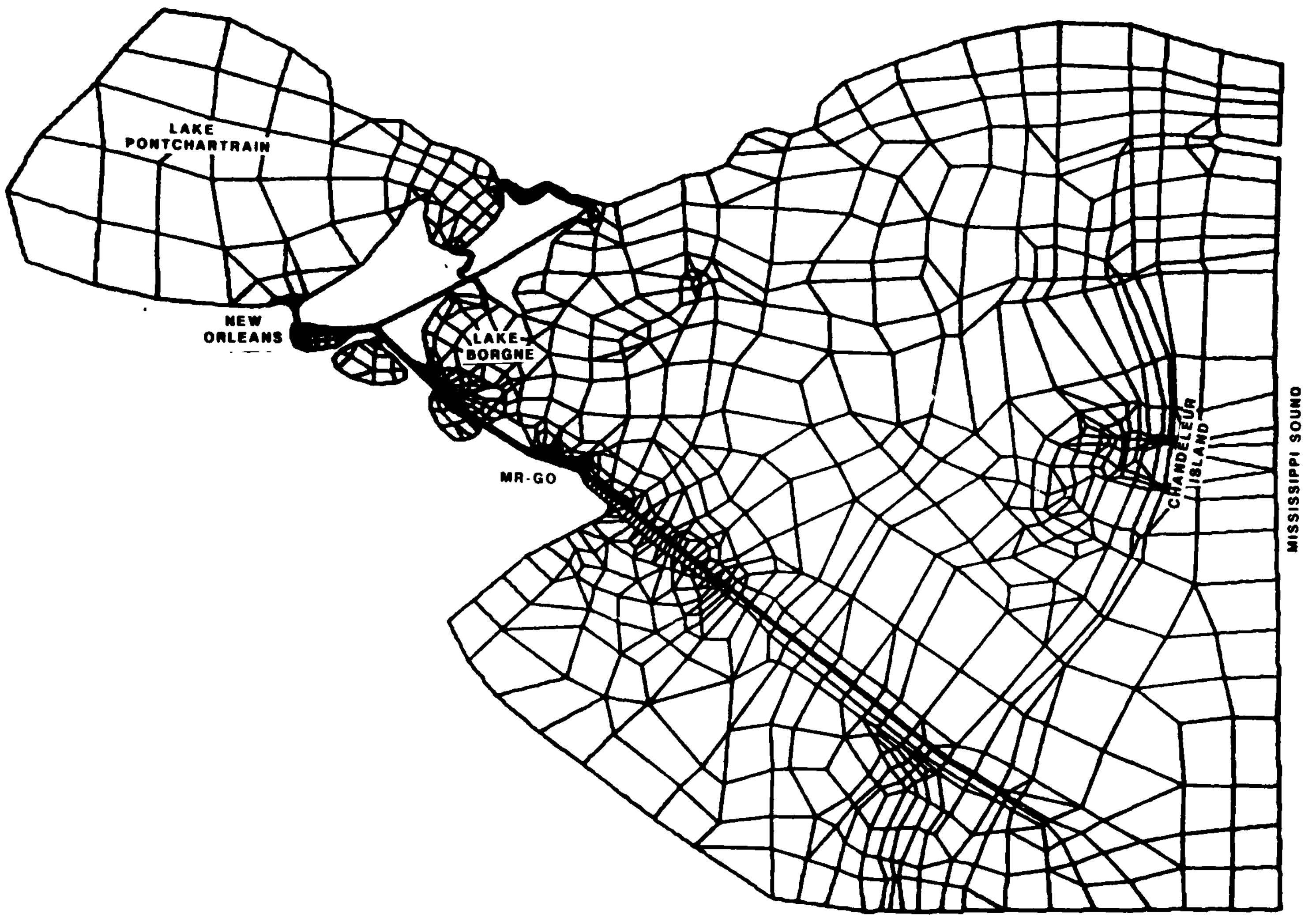


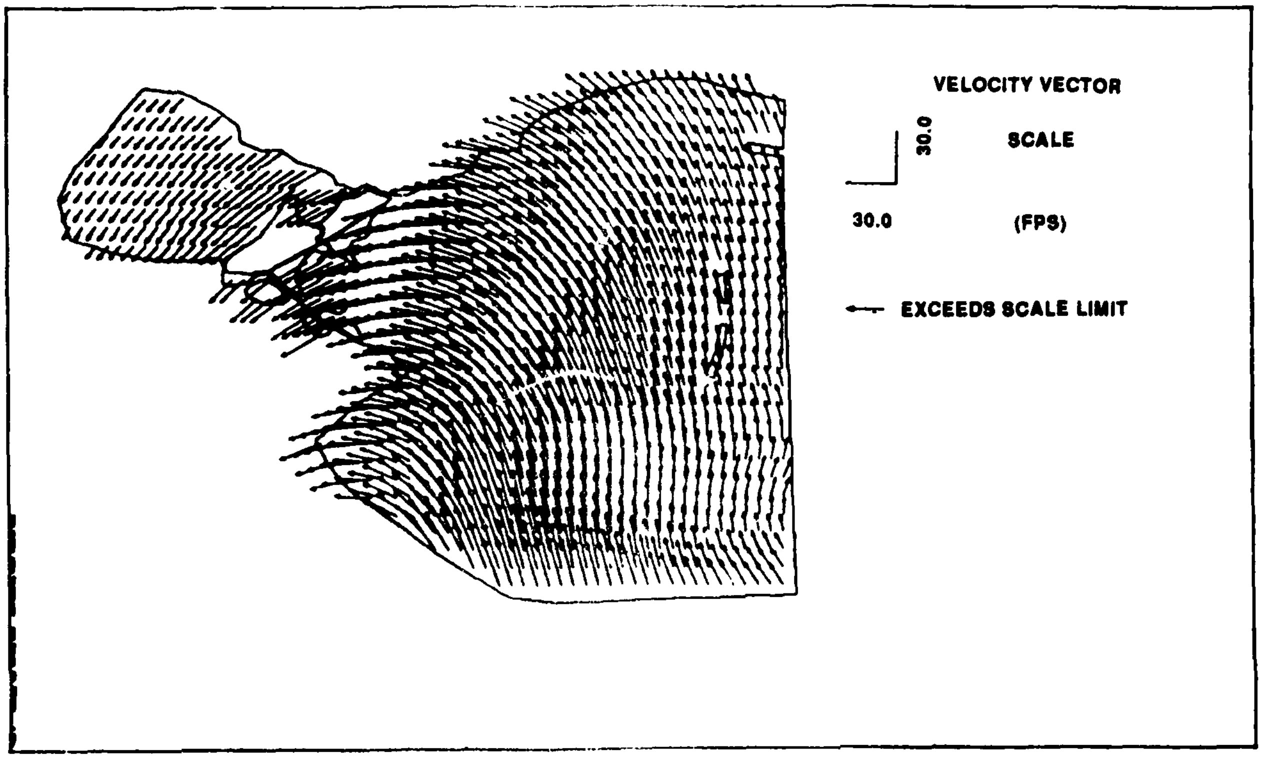
Figure 8. TABS MR-GO two-dimensional computational mesh, revised

two days prior to the actual field event instead of one. This would have eliminated the estimations involved in artificially extending the boundary conditions to allow 36 hours of RMA-2 spin-up. The system response, including Lake Pontchartrain, appeared to necessitate a spin-up time of 36 hours to sufficiently damp inaccuracies from assumed initial conditions.

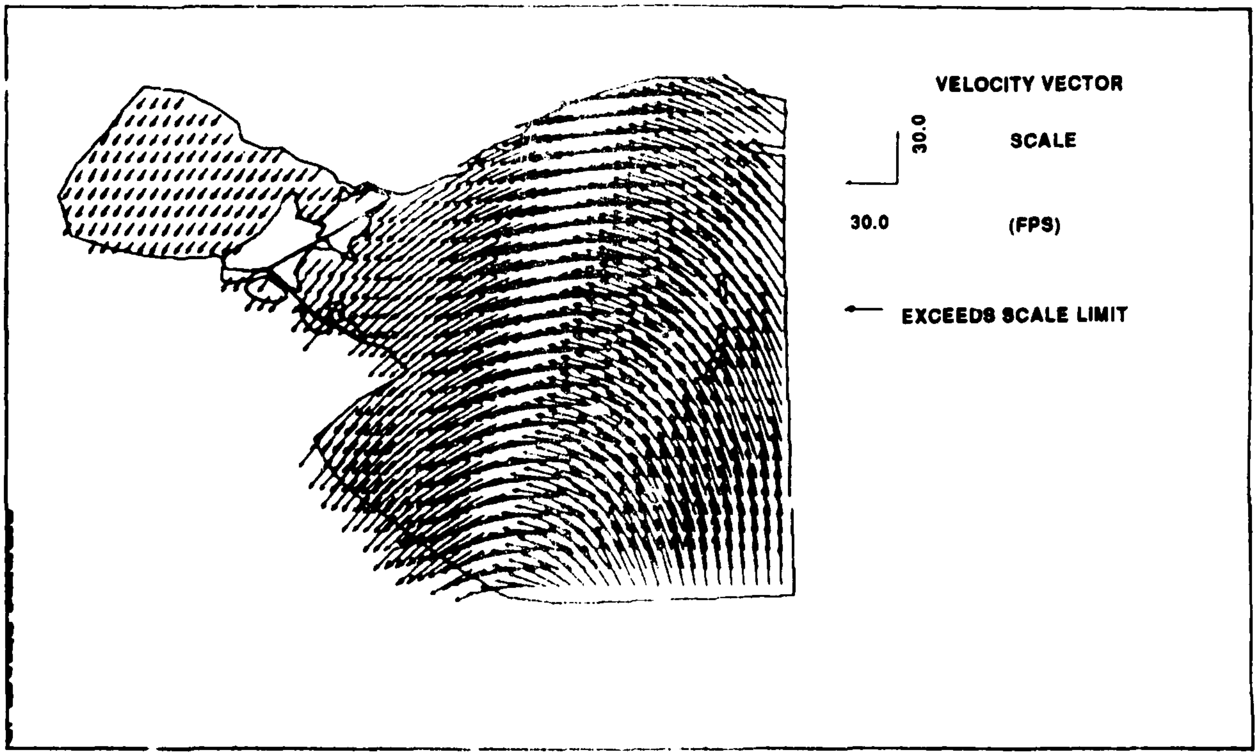
64. In the early stages of developing the hydrodynamic model, the elemental wetting and drying technique was applied to the MR-GO model. Significant improvement in the verification was obtained when the marsh porosity option replaced the elemental wetting and drying option. This emphasizes the important role of marsh areas in the total hydrodynamics of the study area. It is difficult to determine from aerial photography the significance of honeycombed marsh lands. What is the elevation of the marsh, the degree of conveyance through marshes, and what is the tidal prism associated with the marsh? These questions beg an answer and their importance to model results can not be determined with existing data.

65. Diagnostic tests indicated that the hydrodynamic verification was improved by abandoning the conservative approach of average adjustments made to the boundary conditions obtained from the W-MSM results. The approach described in Part III was to develop a procedure that would apply identically to every test condition, including production runs. However, this approach led to a less than optimum conformance of the farthest gulfward control tide gages to the observed prototype tides. By adjusting the water level boundary conditions on a case by case basis, the water levels verification and velocity magnitudes were improved but the model's velocity phasing discrepancies were unaffected. However, this case by case adjustment technique would have made determination of boundary water level adjustments difficult for any scenarios other than those actually monitored through field investigations.

66. The hydrodynamic verification could have been improved further with more accurate temporal and spatial wind variations. To test this hypothesis, a computed wind field option was added to the RMA-2 model which would provide a time and spatially varying wind field for the model. It involved a statistical technique of representing the frontal passage as a distribution function by incorporating the temporal wind data from the New Orleans Airport station and the Chandeleur Island station. The computed wind field was used to demonstrate wind effects but does not provide an adequate substitute for additional field data. Figures 9a and 9b show a representative time and spatially



a. Hour 50.0



b. Hour 55.0

Figure 9. Numerical simulation of time and spatially varying wind during a frontal passage

varying storm event (wind velocity magnitude and direction) simulating a frontal passage in RMA-2. This figure illustrates the linear combination of the wind fields of four storms as given at model hours 50 and 55 (coincident with the field survey). The RMA-2 model has the capability of generating spatial variations in wind speed and direction for each time step based upon a user specified set of criteria for the storm(s). These criteria include factors such as: storm path, orientation of the storm along the path, storm speed, shape, and rate of decay. The RMA-2 model was run with the various wind data available: New Orleans Airport National Weather Service station and the computed wind field which used both the New Orleans Airport data and the Chandeleur Island Buoy Station from the National Climate Data Center. Figure 10 shows the sensitivity of the RMA-2 model to wind effects at the Shell Beach gap location. This figure demonstrates that the model versus prototype velocity phase relationship is very sensitive to the wind field and that computed winds gave a much better agreement between prototype and model current data.

Sedimentation Issues

67. The lack of prototype sedimentation LANDSAT analysis has already been addressed.

68. Why was there so little sedimentation effect in widening the gaps? One possibility is that the existing condition bathymetry already had several partially obstructed connections with Lake Borgne, which meant that the relative impact of the plan at the gaps was possibly diminished.

69. The impact of the improved hydrodynamic verification on the sediment transport verification is believed to be significant. Had the hydrodynamic model final results been used, the sedimentation results might have been different. We are unable to draw any conclusions about sedimentation with the gaps widened.

Diagnostic Testing

70. The numerical model was run through a series of tests in an attempt to identify the potential source(s) of inconsistency between the model and the field velocity measurements. These tests included sensitivity adjustments of the following factors:

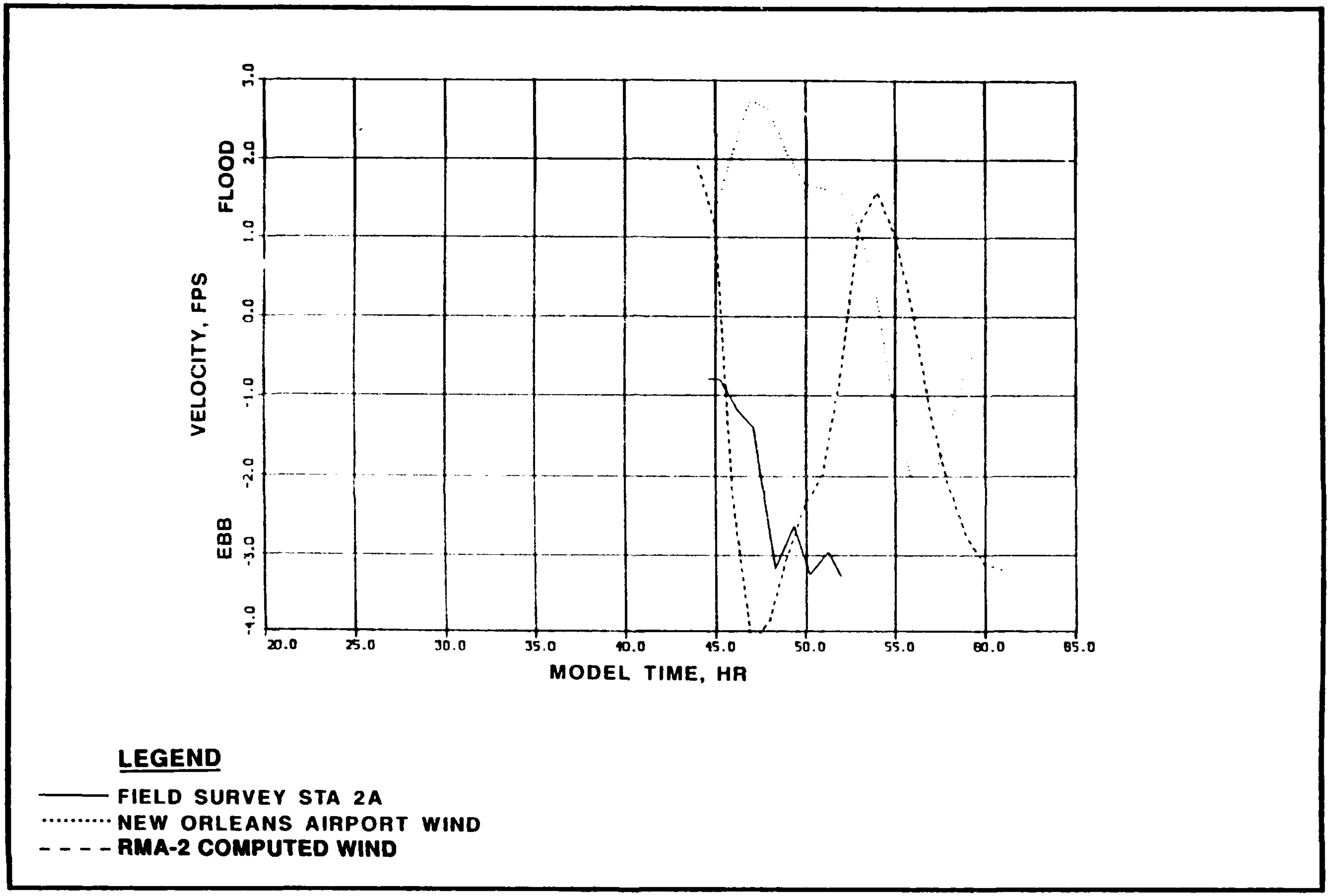


Figure 10. RMA-2 sensitivity to wind at the Shell Beach gap location

a. Geometry

(1). Width of the gaps between Lake Borgne and MR-GO

(2). Width of MR-GO channel

(3). Depth of MR-GO channel

(4). Added additional small channel connections

(5). Smoothed shoreline boundaries

(6). Smoothed some sharp depth gradients in gulf

(7). Marsh porosity geometry parameters

(8). Added tidal marsh storage adjacent MR-GO (3 locations)

(9). Conversion of area between Breton Sound and Lake Borgne from land to marsh in model representation

b. Boundary Conditions

(1). Extended the model spin-up time

(2). Adjusted the gulf BC to better reproduce tides at control stations

(3). Adjusted the initial water surface elevation

c. Coefficient Adjustments

(1). Bottom roughness (Manning's n)

(2). Eddy viscosities

d. Wind stress conditions

(1). Wind stress formulation options

(2). New Orleans wind data applied uniformly to mesh

(3). Chandeleur Island wind applied uniformly to mesh

(4). Spatial distribution of wind associated with frontal passage based on the two wind stations above and surface weather analysis charts

71. Of all of these sensitivity runs the only adjustment which had a significant improvement in the current velocities in question was the use of the frontal passage spatially and temporally varying wind field. This impact was dramatically greater than any of the other influences, with regard to both the magnitude and the phasing of the currents.

72. The evidence is inconclusive as to whether the numerical hydrodynamic model was performing properly with regard to basic tidal propagation or wind responses. Even with the insight into the sensitivity of the model to the spatial wind field, there is insufficient wind data to accurately define that field. The possibility remains that with the proper wind forcing the

model performance could be found to be already within acceptable limits of accuracy. Based on extensive USAEWES modeling experience there is no reason to expect the verification to be less than adequate with the level of sensitivity runs performed unless one of the basic forcing functions (wind) is not properly prescribed.

73. Future modeling in marsh areas will benefit from these lessons learned during the MR-GO study. The computational model developed is a good one, and with the insights of this work available, it can become a valuable tool for USACE activities in the area (for example, freshwater diversion into Lake Pontchartrain).

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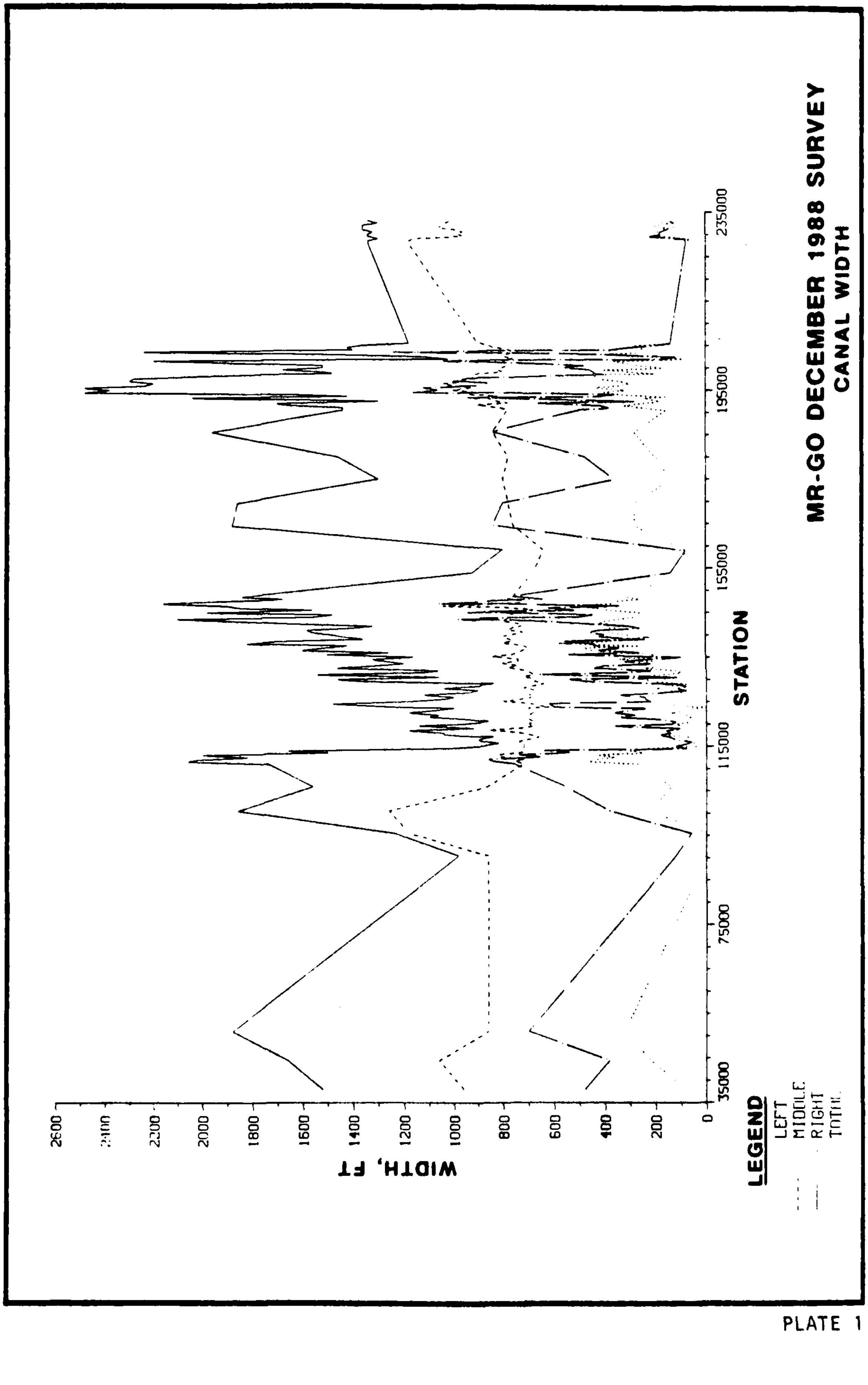
MR-GO DECEMBER 1988 SURVEY
CANAL WIDTH
STATION
WIDTH, FT
2600
2200
2000
1800
1600
1400
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35000
75000
115000
155000
195000
235000
LEGEND
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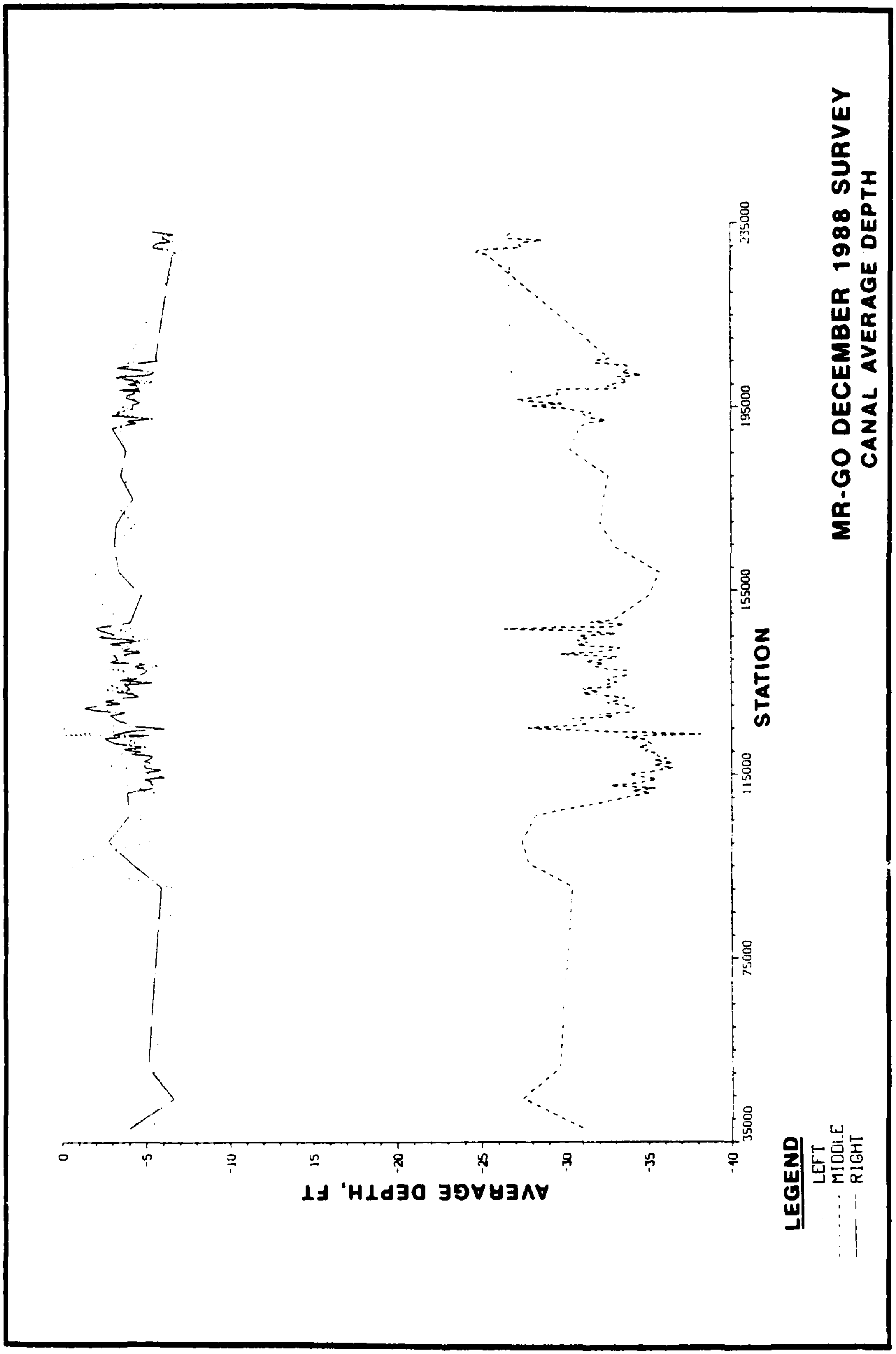
MIDDLE
RIGHT
TOTAL

PLATE 1


MR-GO DECEMBER 1988 SURVEY
CANAL AVERAGE DEPTH
AVERAGE DEPTH, FT
STATION
0
-5
-10
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LEGEND
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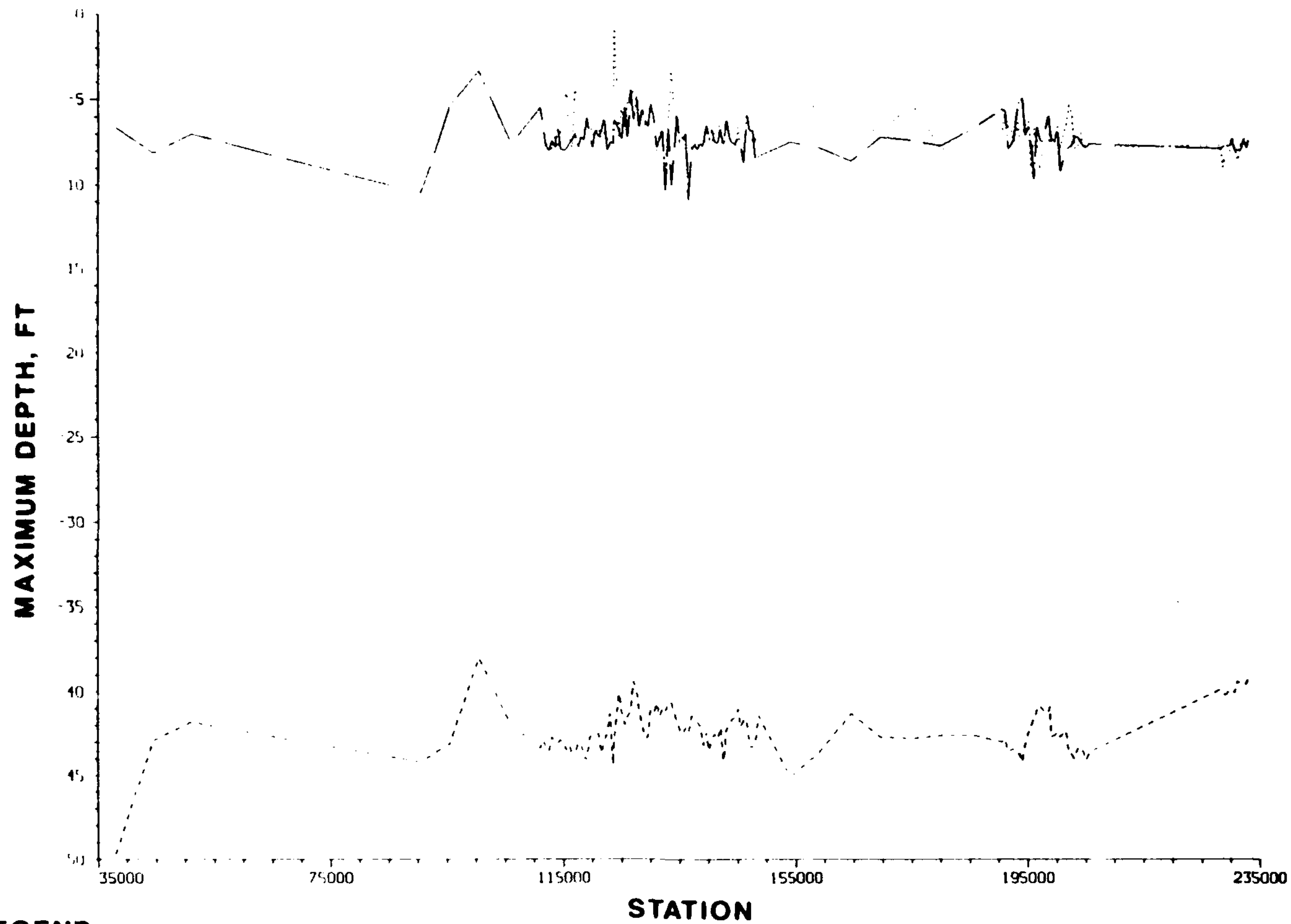
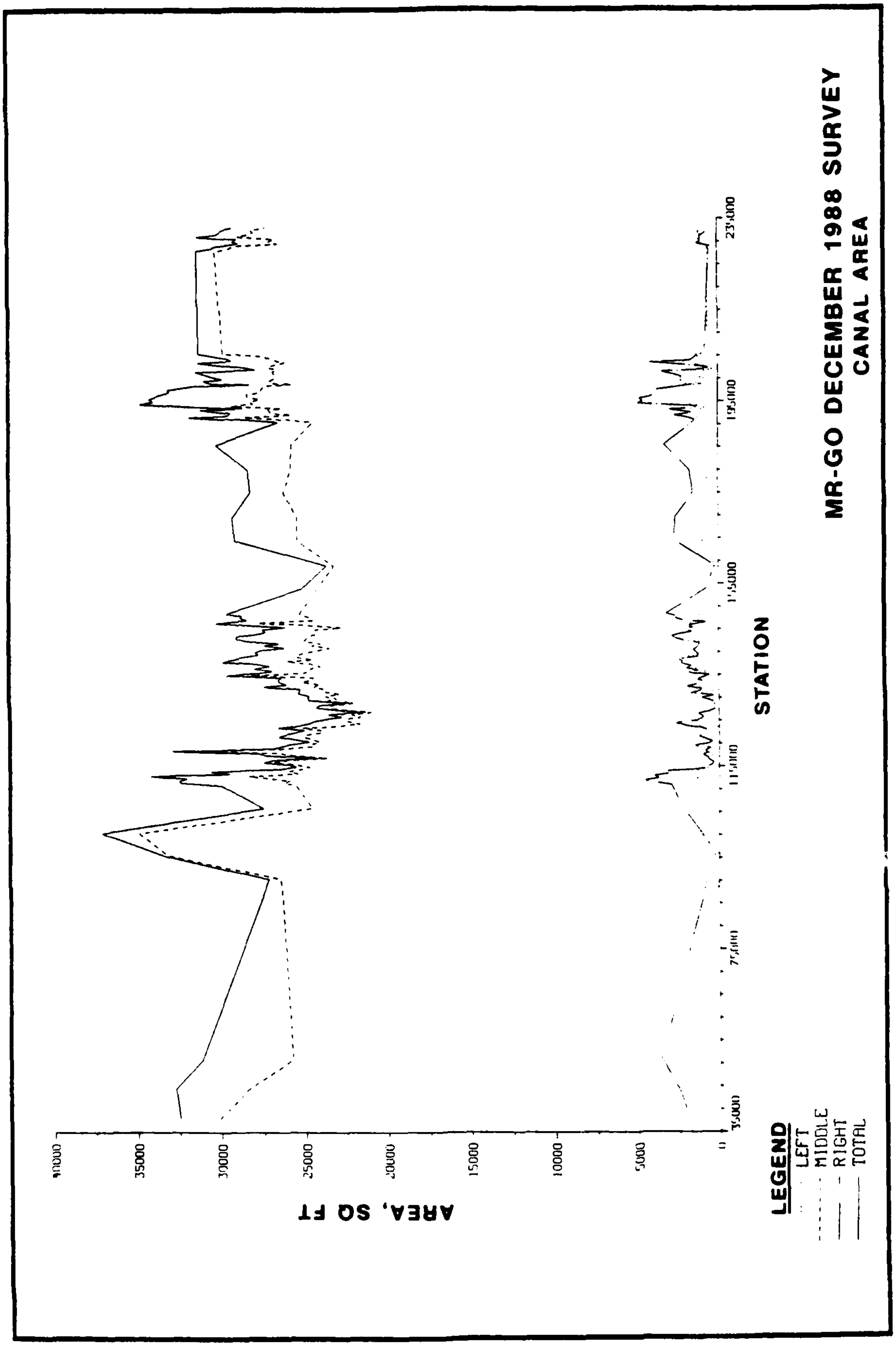
PLATE 2



LEGEND

LEFT
MIDDLE
RIGHT
TOTAL

MR-GO DECEMBER 1988 SURVEY
CANAL MAXIMUM DEPTH


MR-GO DECEMBER 1988 SURVEY
CANAL AREA
STATION
AREA, SQ FT
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MIDDLE
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25000
20000
15000
10000
5000
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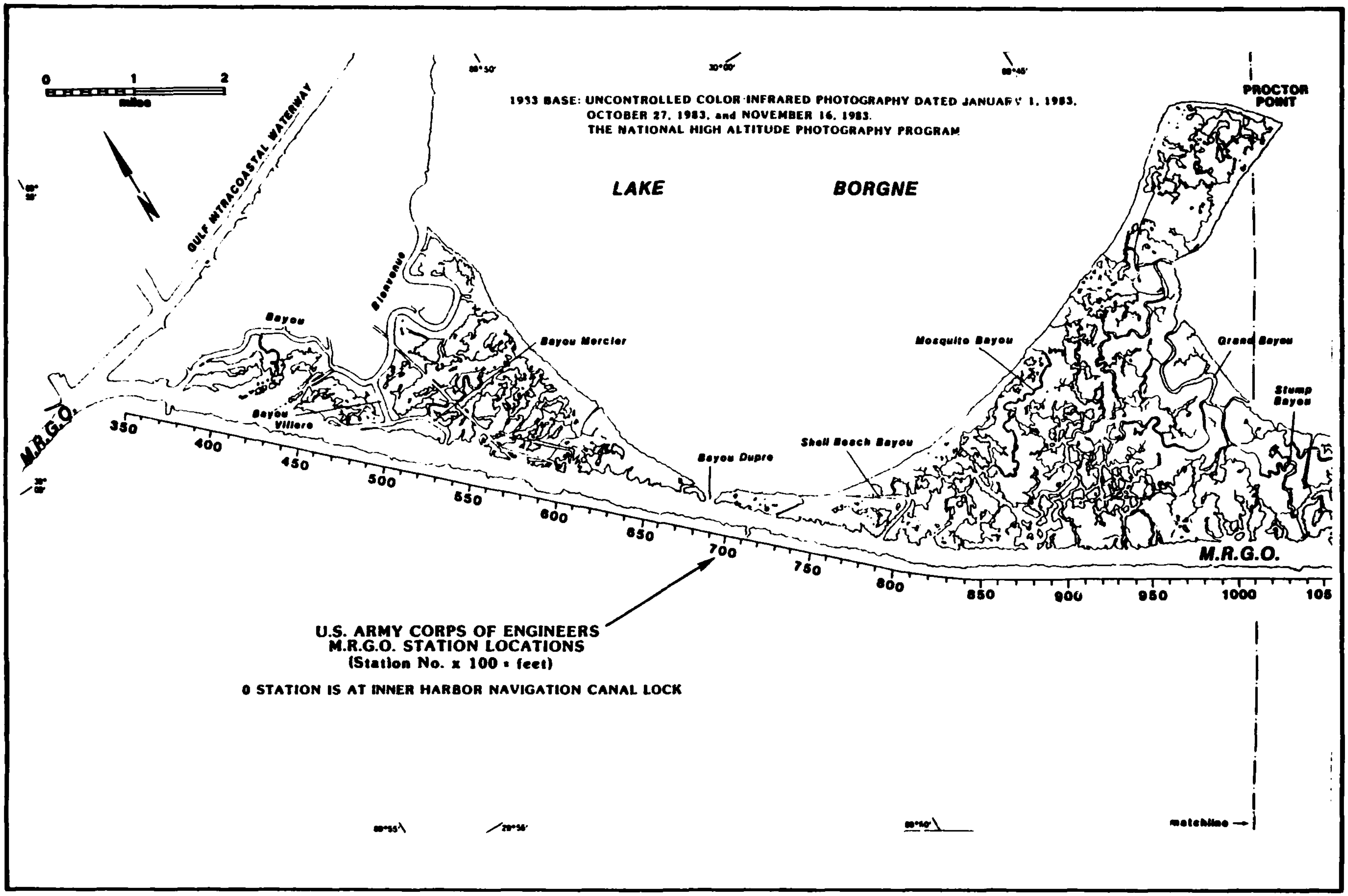
PLATE 4


1953 BASE: UNCONTROLLED COLOR-INFRARED PHOTOGRAPHY DATED JANUARY 1, 1983,
OCTOBER 27, 1983, and NOVEMBER 16, 1983.
THE NATIONAL HIGH ALTITUDE PHOTOGRAPHY PROGRAM
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BORGNE
PROCTOR POINT
Bayou
Bienvenue
Bayou Mercier
Bayou Villere
Bayou Dupre
Shell Beach Bayou
Mosquito Bayou
Grand Bayou
Stump Bayou
M.R.G.O.
M.R.G.O.
350
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1000
105
U.S. ARMY CORPS OF ENGINEERS
M.R.G.O. STATION LOCATIONS
(Station No. x 100 = feet)
0 STATION IS AT INNER HARBOR NAVIGATION CANAL LOCK
matchline

PLATE 5

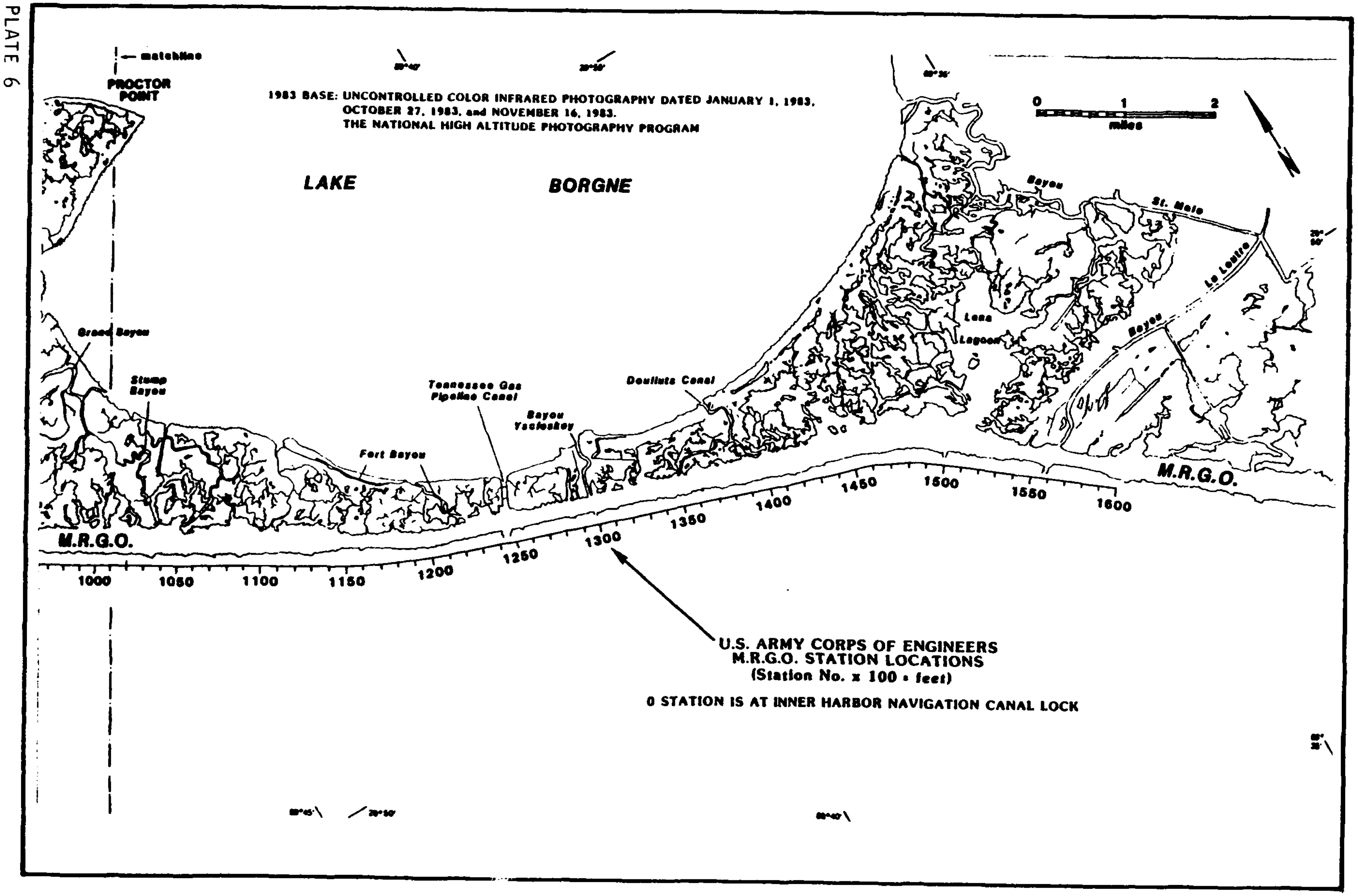
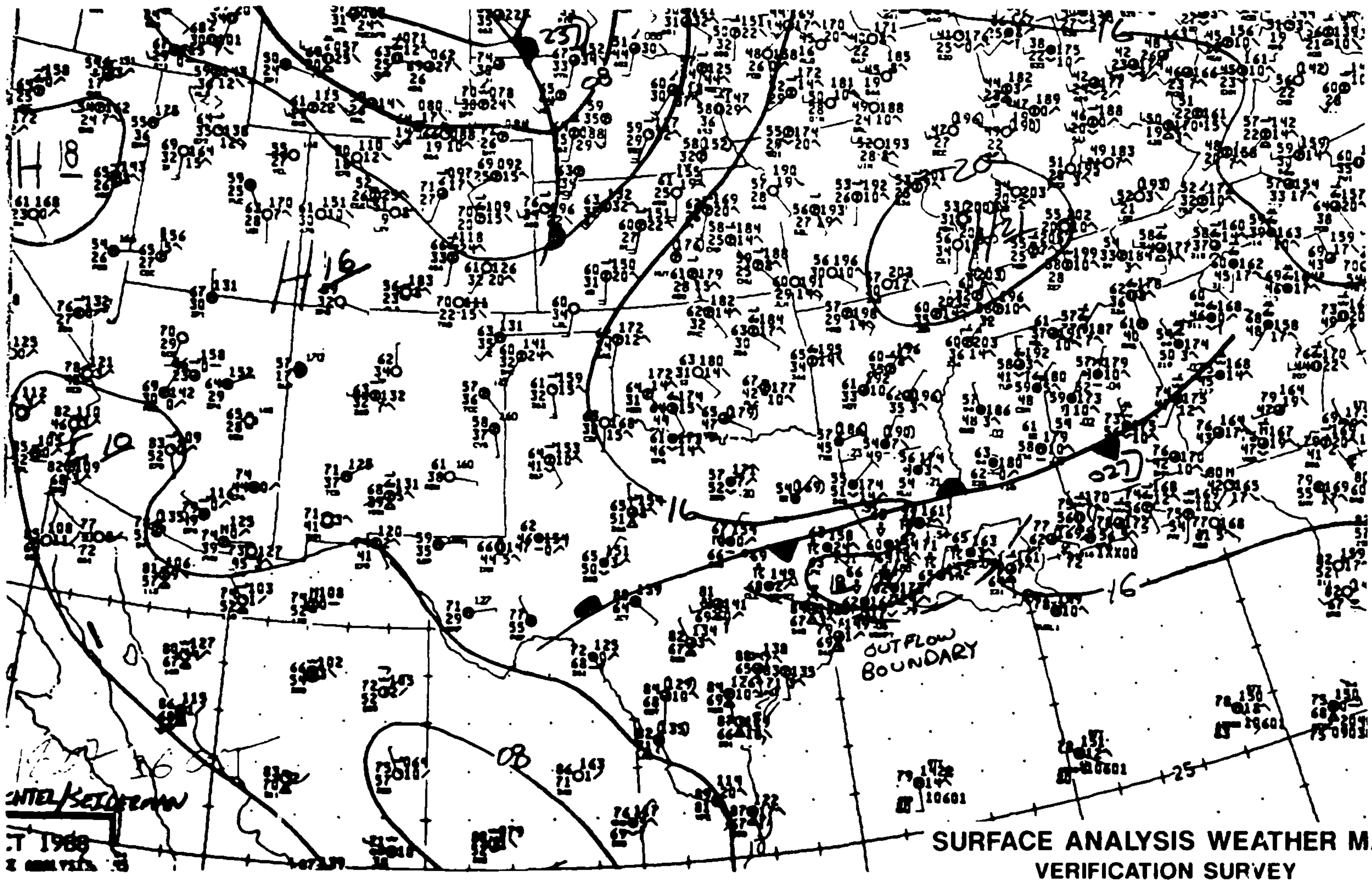

matchline
PROCTOR POINT
1983 BASE: UNCONTROLLED COLOR INFRARED PHOTOGRAPHY DATED JANUARY 1, 1983,
OCTOBER 27, 1983, and NOVEMBER 16, 1983.
THE NATIONAL HIGH ALTITUDE PHOTOGRAPHY PROGRAM
LAKE
BORGNE
0 1 2
miles
Grand Bayou
Stump Bayou
Fort Bayou
Tennessee Gas Pipeline Canal
Bayou Yscloskey
Doullut's Canal
Lena Lagoon
Bayou
St. Malo
Bayou
La Loutre
M.R.G.O.
M.R.G.O.
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
U.S. ARMY CORPS OF ENGINEERS
M.R.G.O. STATION LOCATIONS
(Station No. x 100 = feet)
0 STATION IS AT INNER HARBOR NAVIGATION CANAL LOCK

PLATE 6



*NOTE: 1800 GMT = 1200 CST

SURFACE ANALYSIS WEATHER MAP
VERIFICATION SURVEY
10-26-1988 1800 GMT*

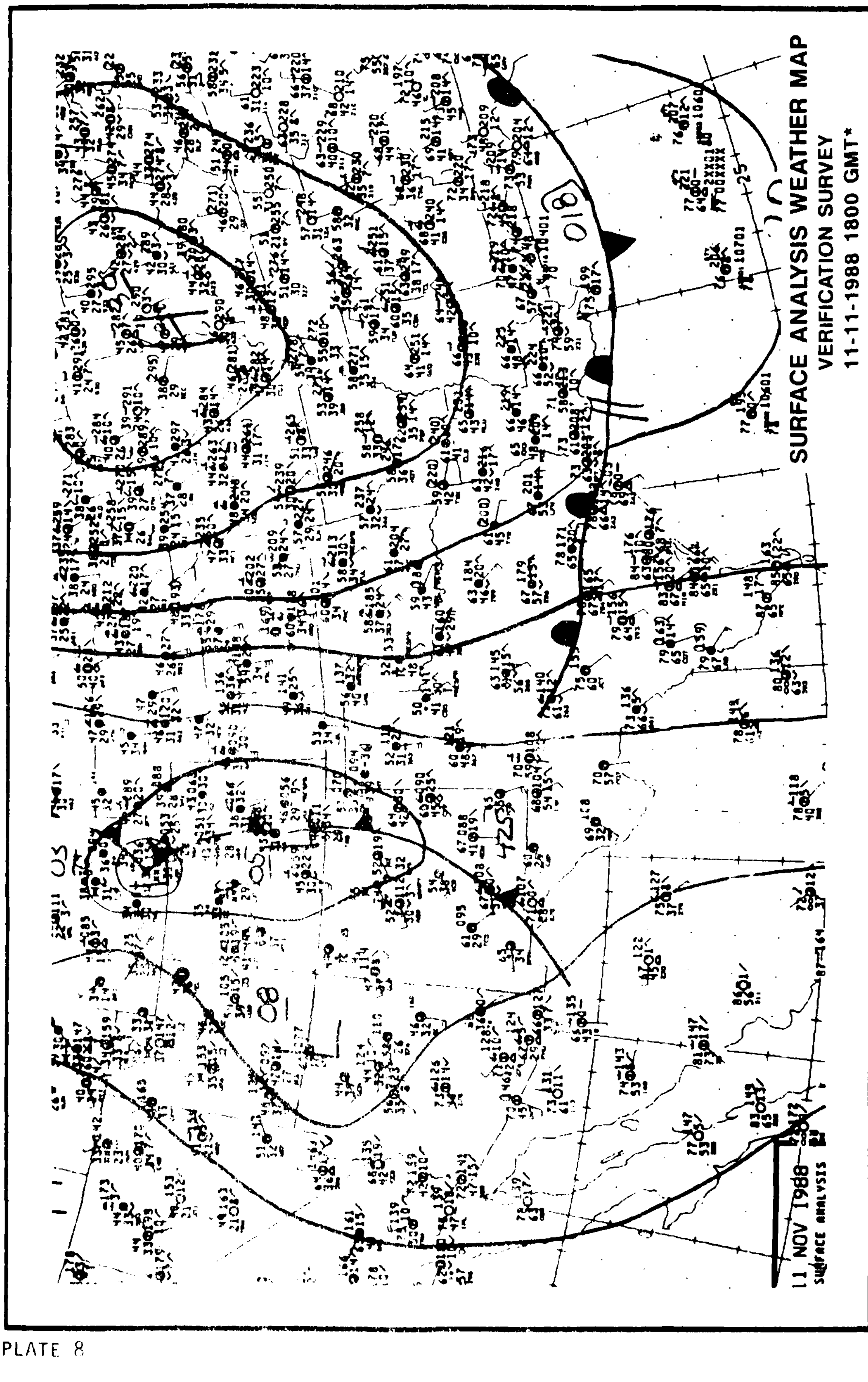

SURFACE ANALYSIS WEATHER MAP
VERIFICATION SURVEY
11-11-1988 1800 GMT*
11 NOV 1988
SURFACE ANALYSIS

PLATE 8

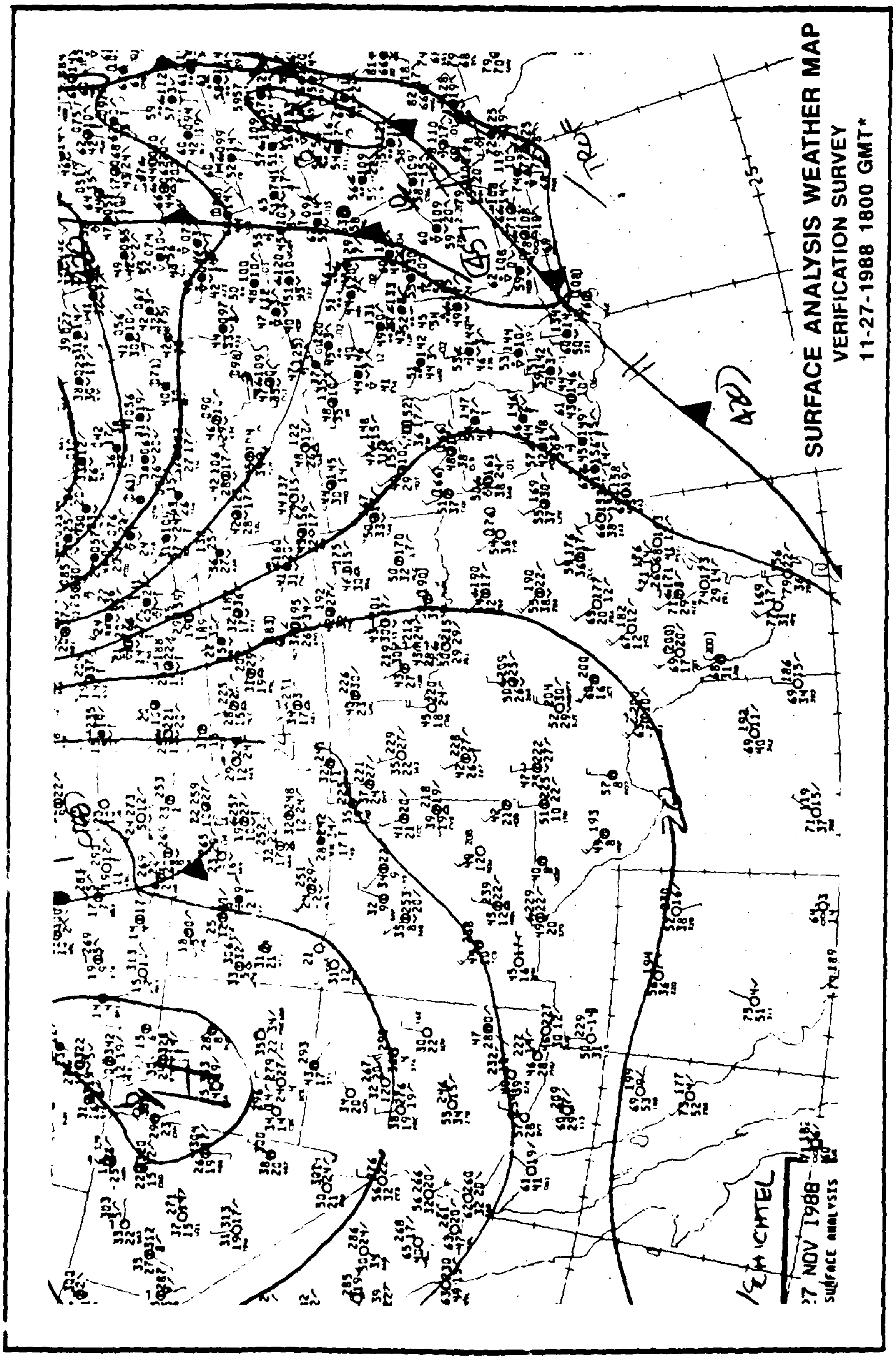
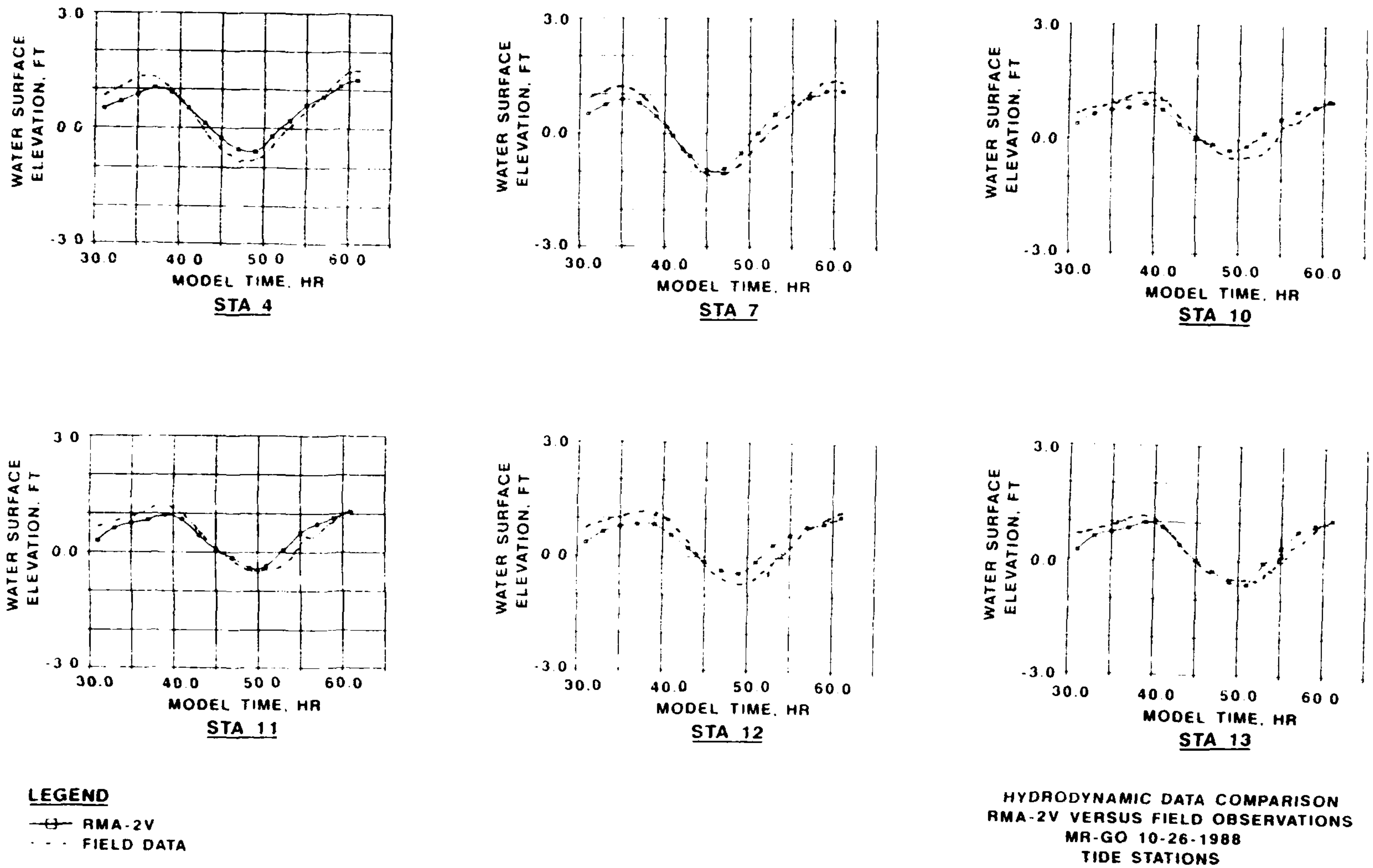
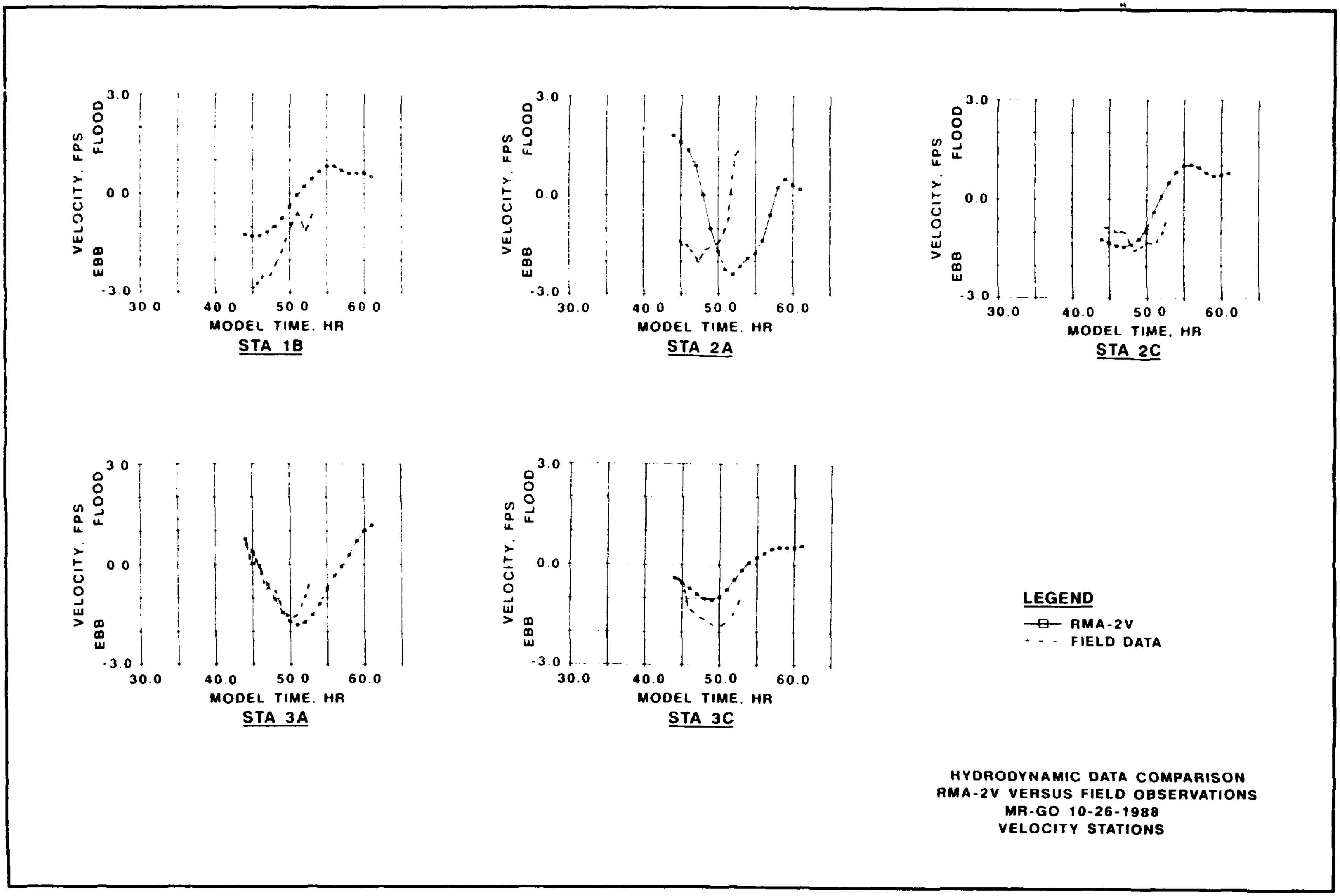
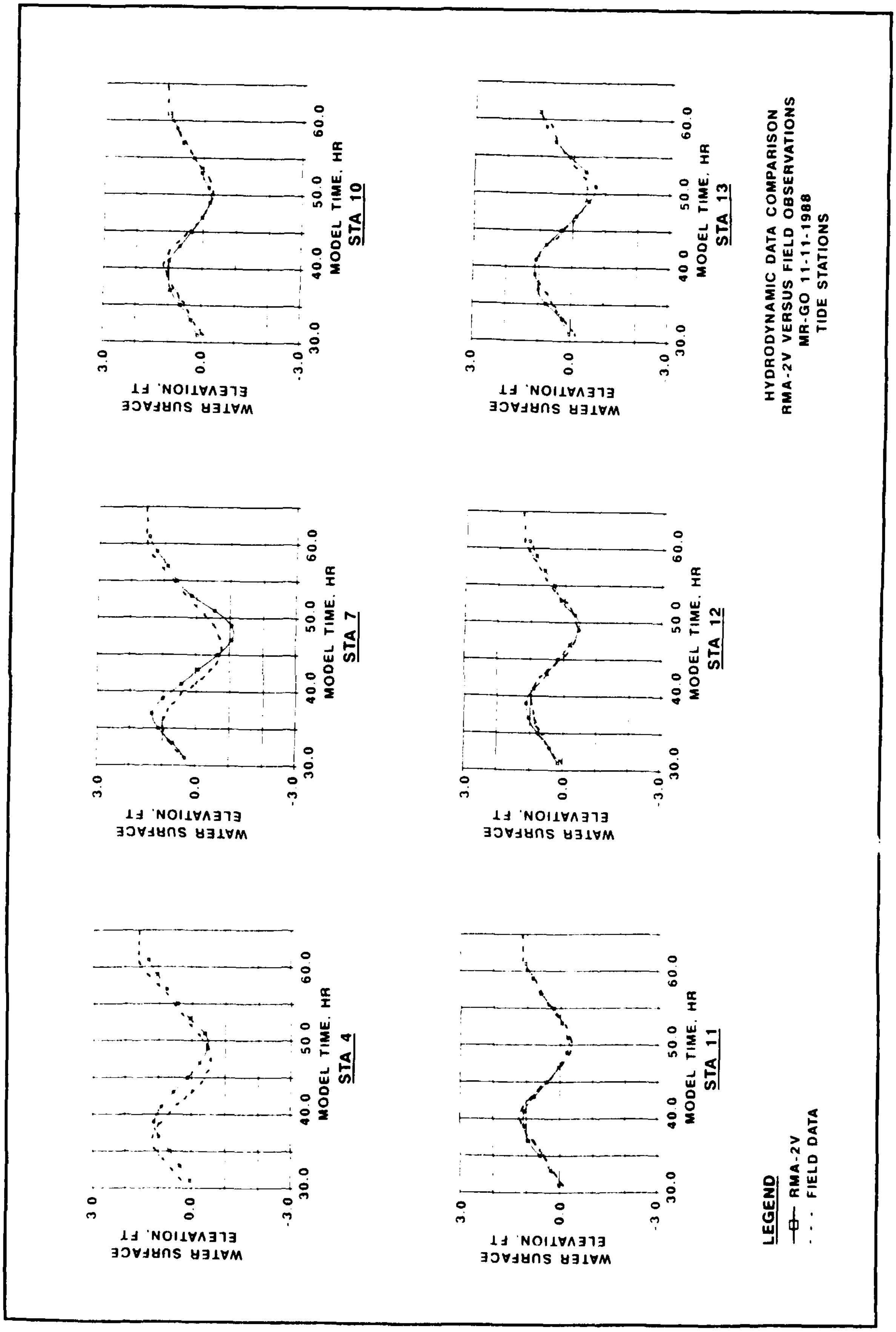

SURFACE ANALYSIS WEATHER MAP
VERIFICATION SURVEY
11-27-1988 1800 GMT*
27 NOV 1988
SURFACE ANALYSIS

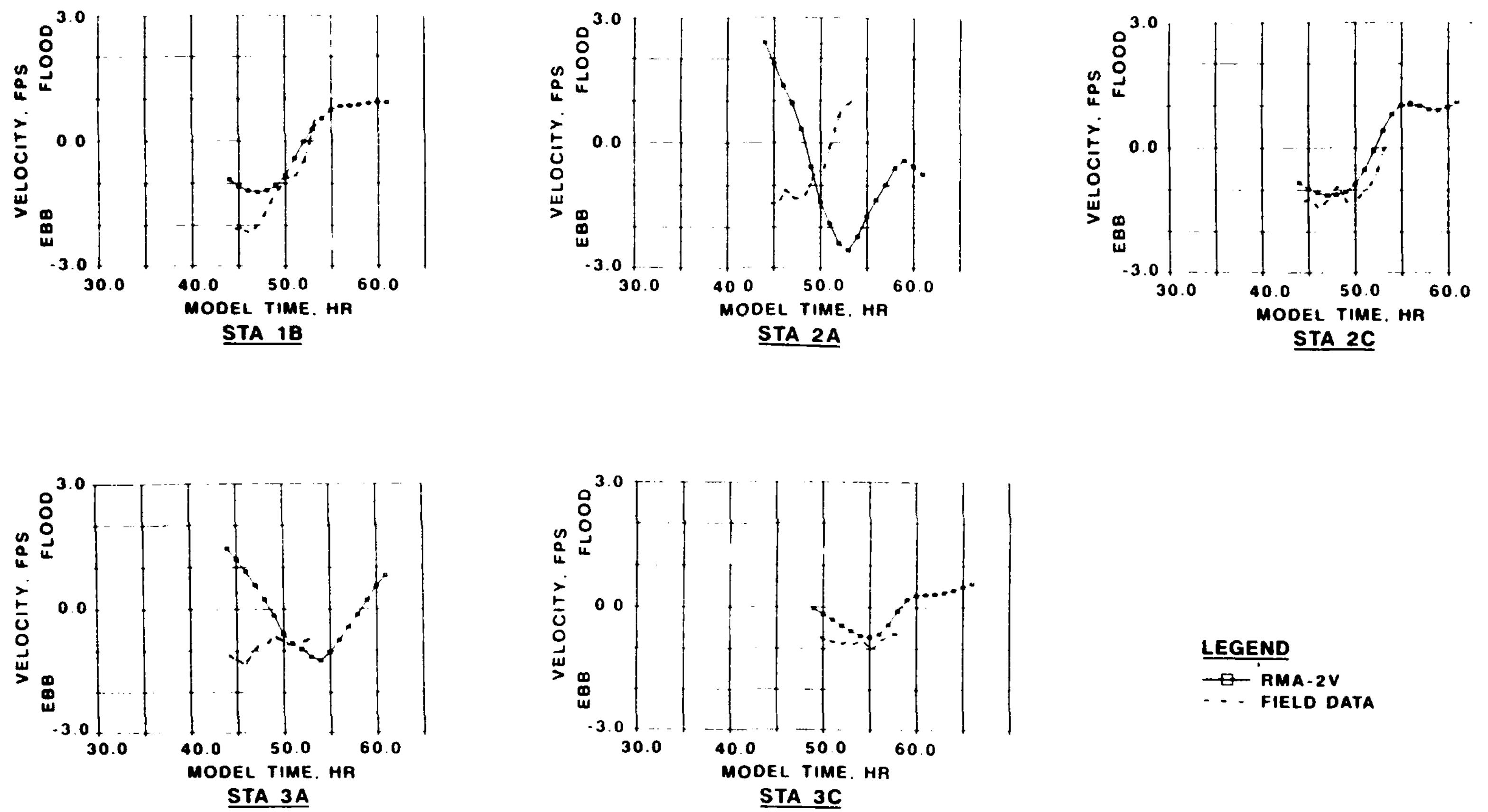
PLATE 9



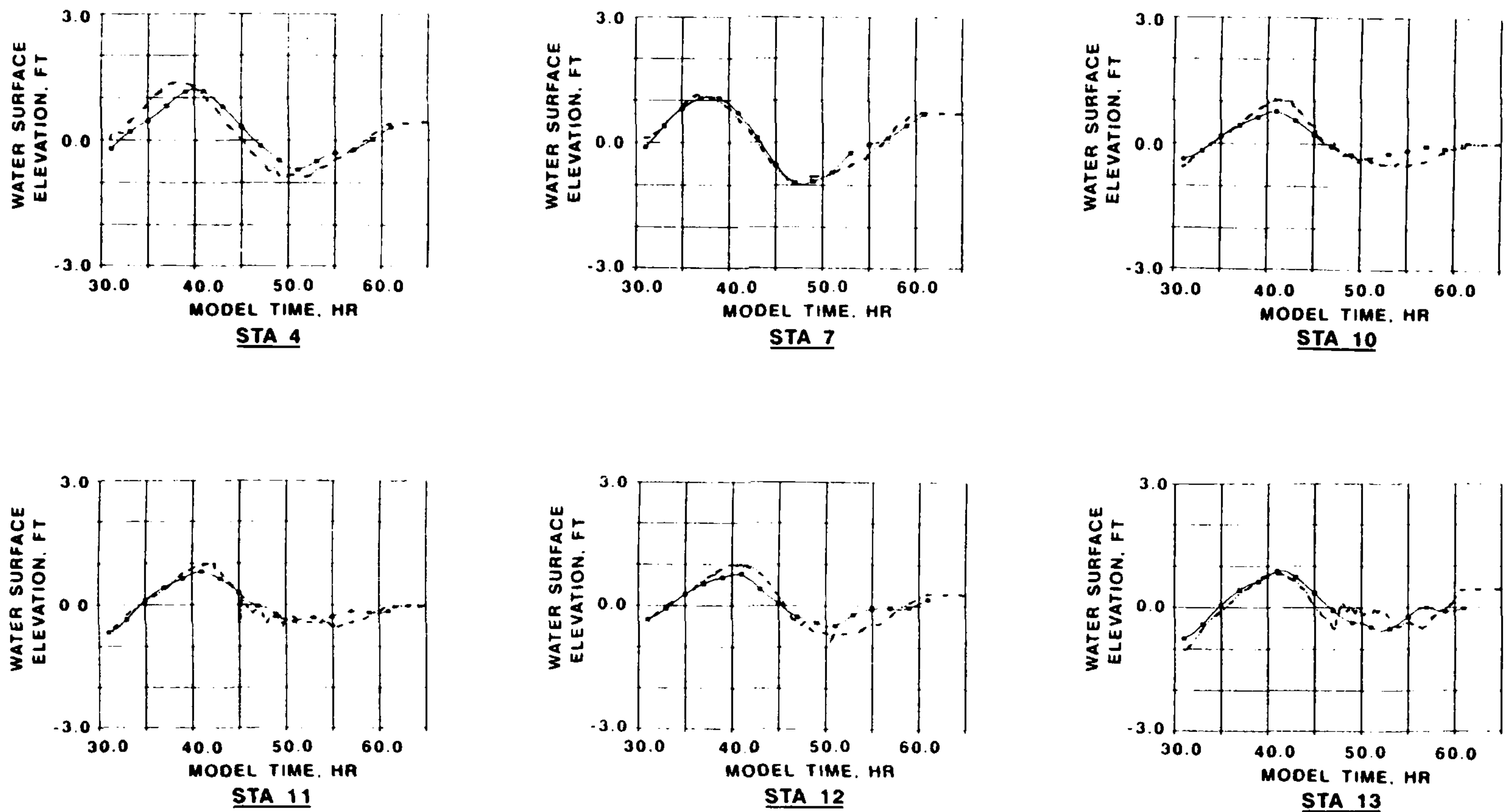
HYDRODYNAMIC DATA COMPARISON
RMA-2V VERSUS FIELD OBSERVATIONS
MR-GO 10-26-1988
TIDE STATIONS


VELOCITY, FPS
FLOOD
EBB
3.0
0.0
-3.0
30.0
40.0
50.0
60.0
MODEL TIME, HR
STA 1B
STA 2A
STA 2C
STA 3A
STA 3C
LEGEND
RMA-2V
FIELD DATA
HYDRODYNAMIC DATA COMPARISON
RMA-2V VERSUS FIELD OBSERVATIONS
MR-GO 10-26-1988
VELOCITY STATIONS


HYDRODYNAMIC DATA COMPARISON
RMA-2V VERSUS FIELD OBSERVATIONS
MR-GO 11-11-1988
TIDE STATIONS
LEGEND
RMA-2V
FIELD DATA
STA 4
STA 7
STA 10
STA 11
STA 12
STA 13
MODEL TIME, HR
WATER SURFACE ELEVATION, FT
3.0
0.0
-3.0
30.0
40.0
50.0
60.0



HYDRODYNAMIC DATA COMPARISON
RMA-2V VERSUS FIELD OBSERVATIONS
MR-GO 11-11-1988
VELOCITY STATIONS

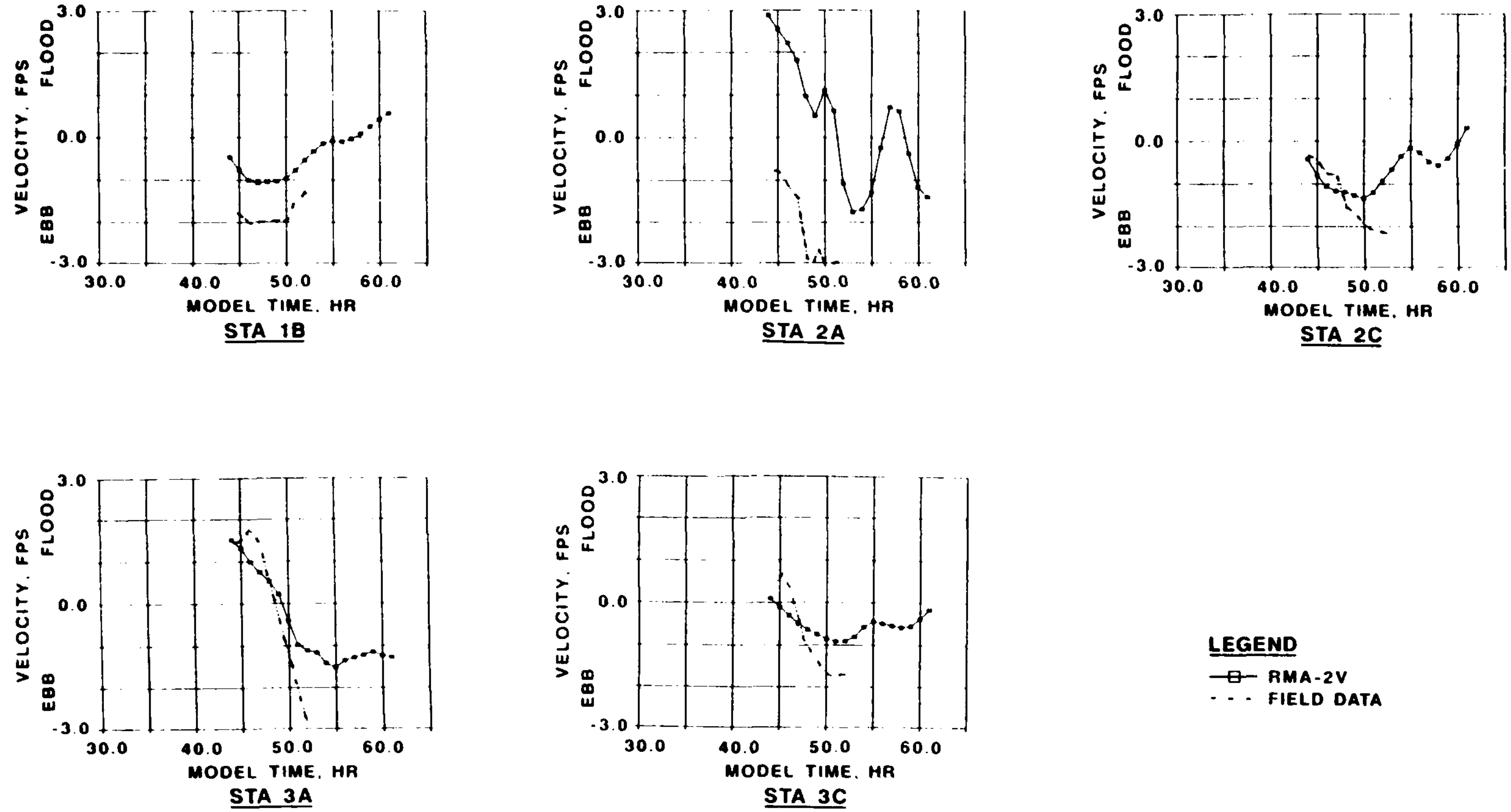


LEGEND

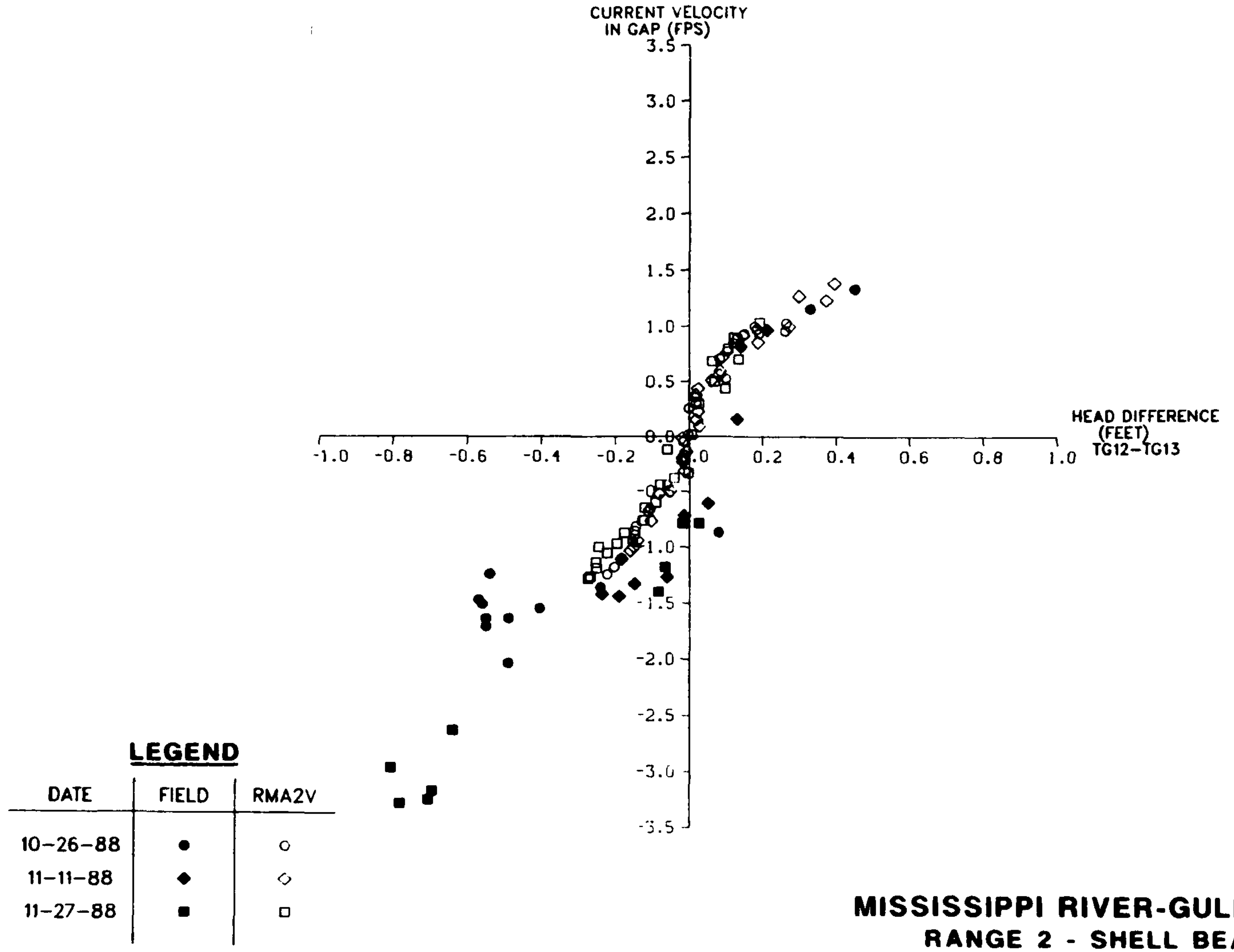
RMA-2V

FIELD DATA

HYDRODYNAMIC DATA COMPARISON
RMA-2V VERSUS FIELD OBSERVATIONS
MR-GO 11-27-1988
TIDE STATIONS

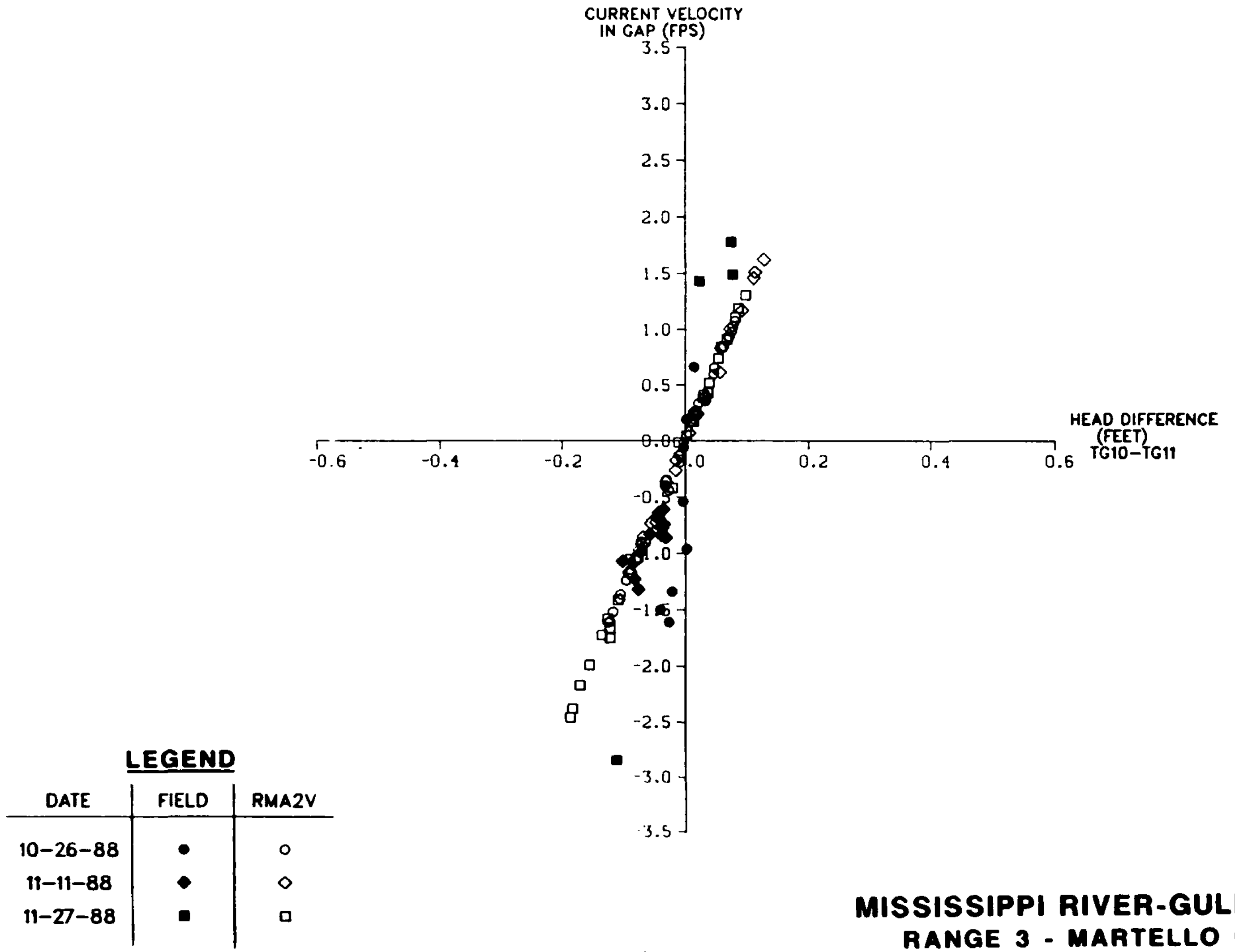


HYDRODYNAMIC DATA COMPARISON
RMA-2V VERSUS FIELD OBSERVATIONS
MR-GO 11-27-1988
VELOCITY STATIONS

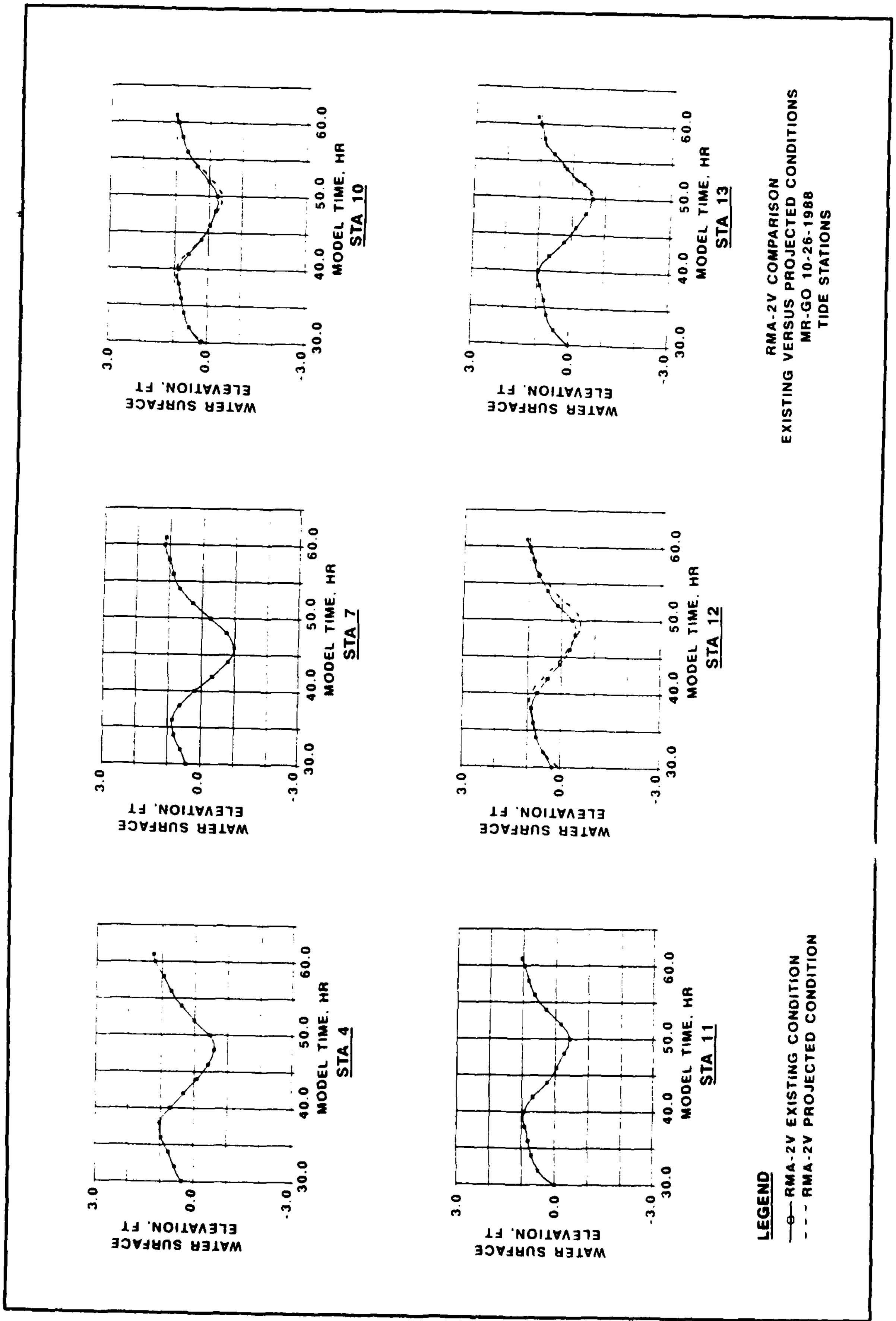


MISSISSIPPI RIVER-GULF OUTLET
RANGE 2 - SHELL BEACH

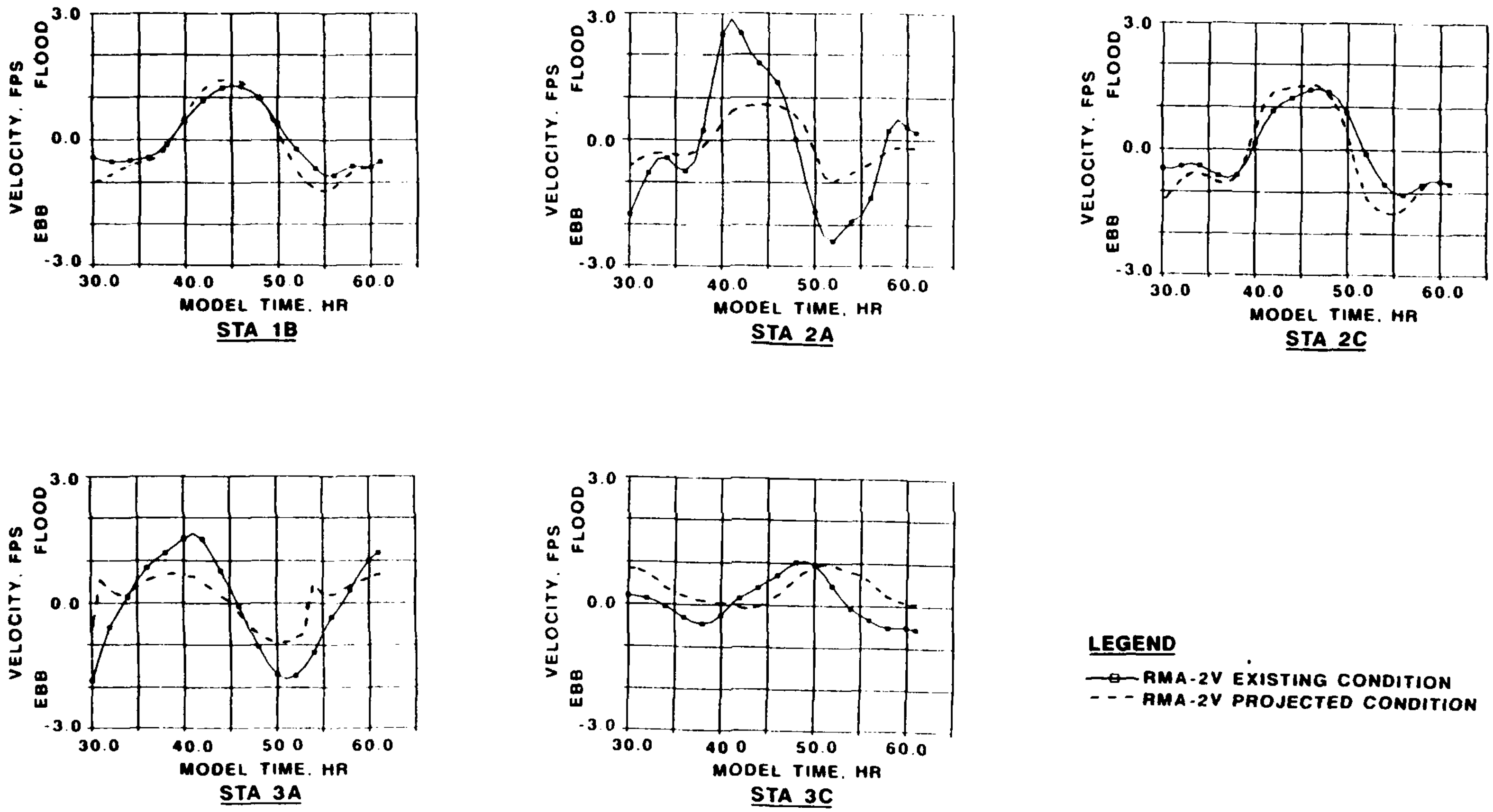
PLATE 16



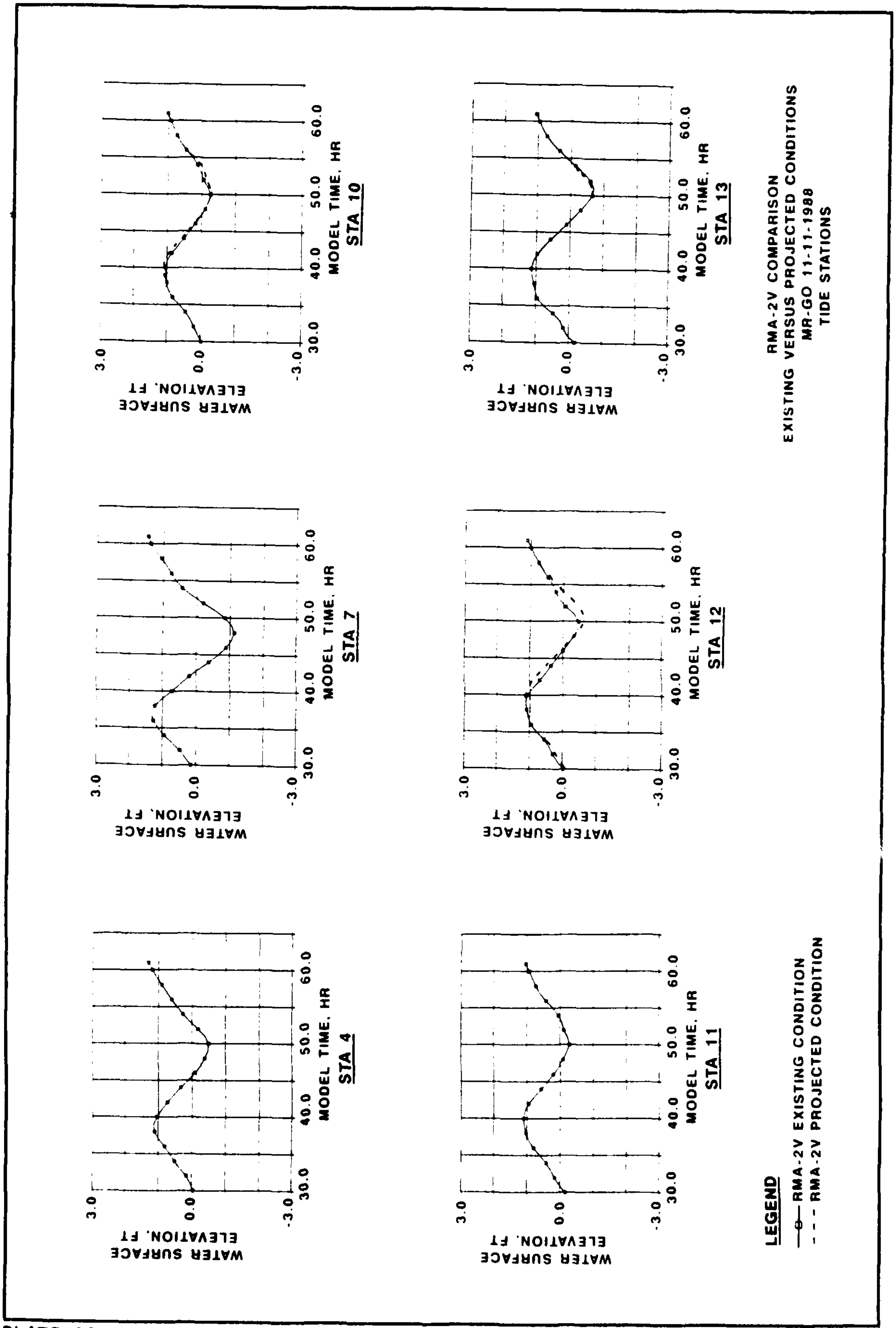
MISSISSIPPI RIVER-GULF OUTLET
RANGE 3 - MARTELLO CASTLE

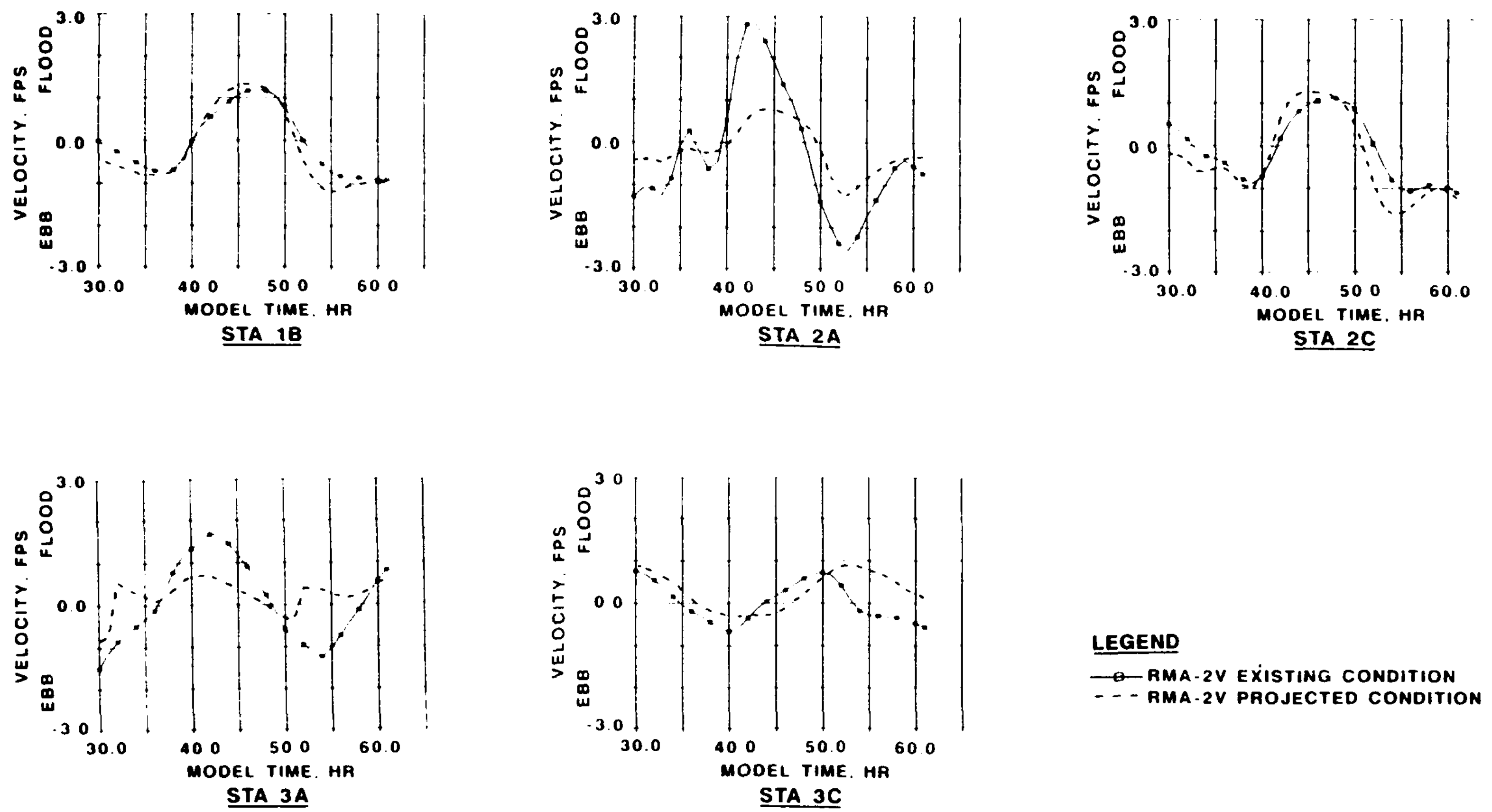


RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO 10-26-1988
TIDE STATIONS
LEGEND
RMA-2V EXISTING CONDITION
RMA-2V PROJECTED CONDITION
WATER SURFACE ELEVATION, FT
MODEL TIME, HR
STA 4
STA 7
STA 10
STA 11
STA 12
STA 13

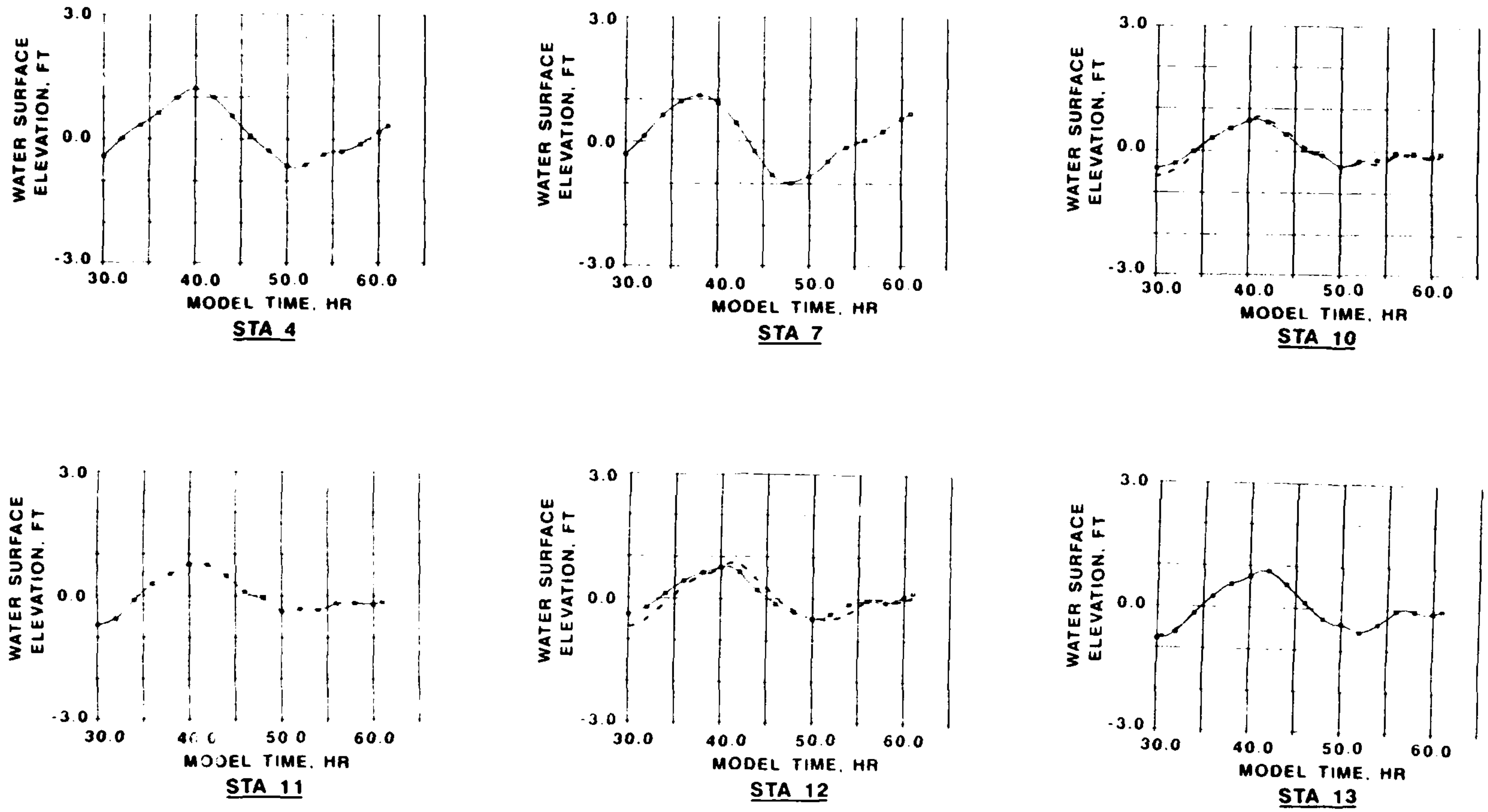


RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO 10-26-1988
VELOCITY STATIONS


RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO 11-11-1988
TIDE STATIONS
LEGEND
RMA-2V EXISTING CONDITION
RMA-2V PROJECTED CONDITION
STA 4
STA 7
STA 10
STA 11
STA 12
STA 13
WATER SURFACE ELEVATION, FT
MODEL TIME, HR
3.0
0.0
-3.0
30.0
40.0
50.0
60.0



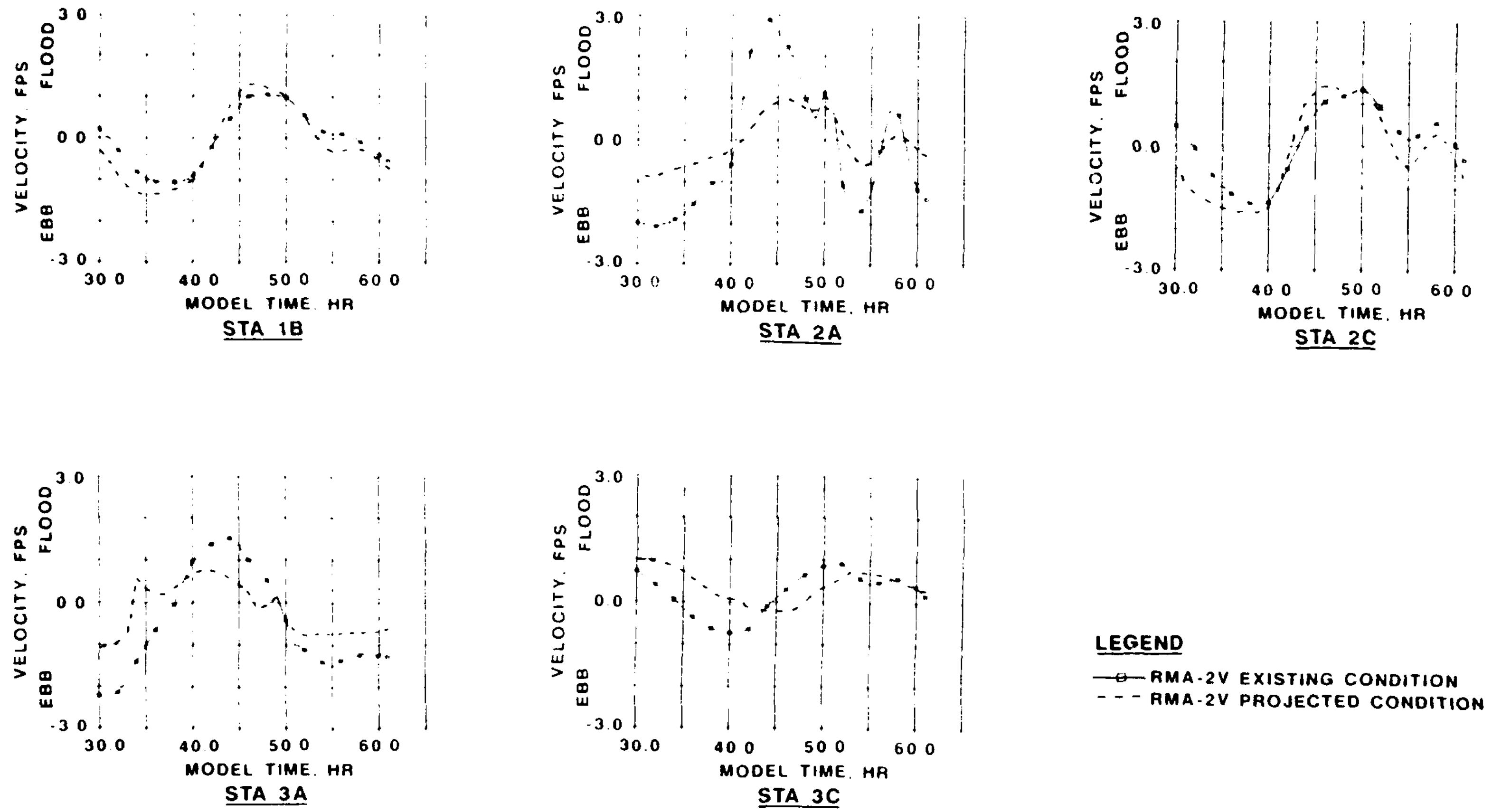
RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO 11-11-1988
VELOCITY STATIONS



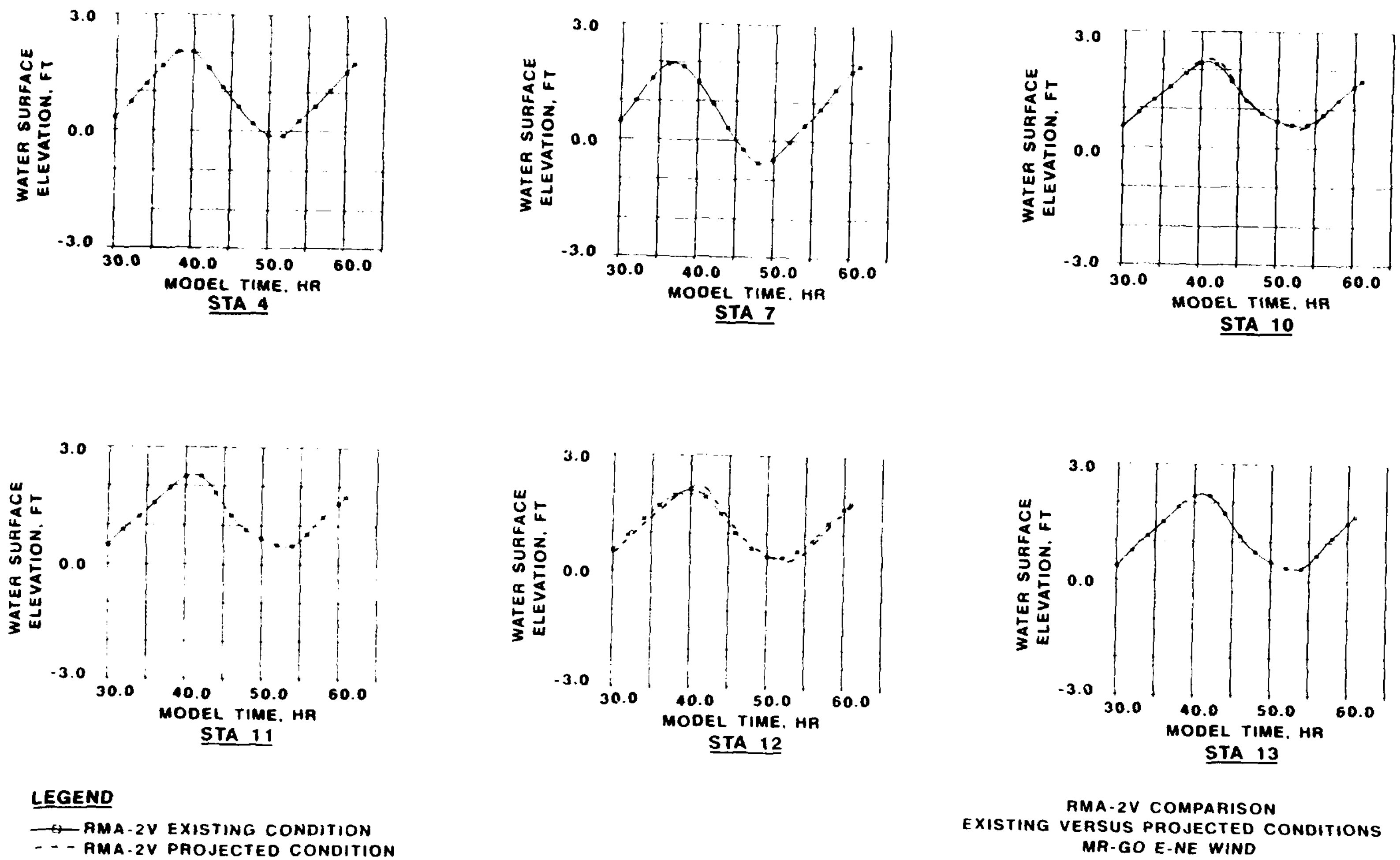
LEGEND

- RMA-2V EXISTING CONDITION
- RMA-2V PROJECTED CONDITION

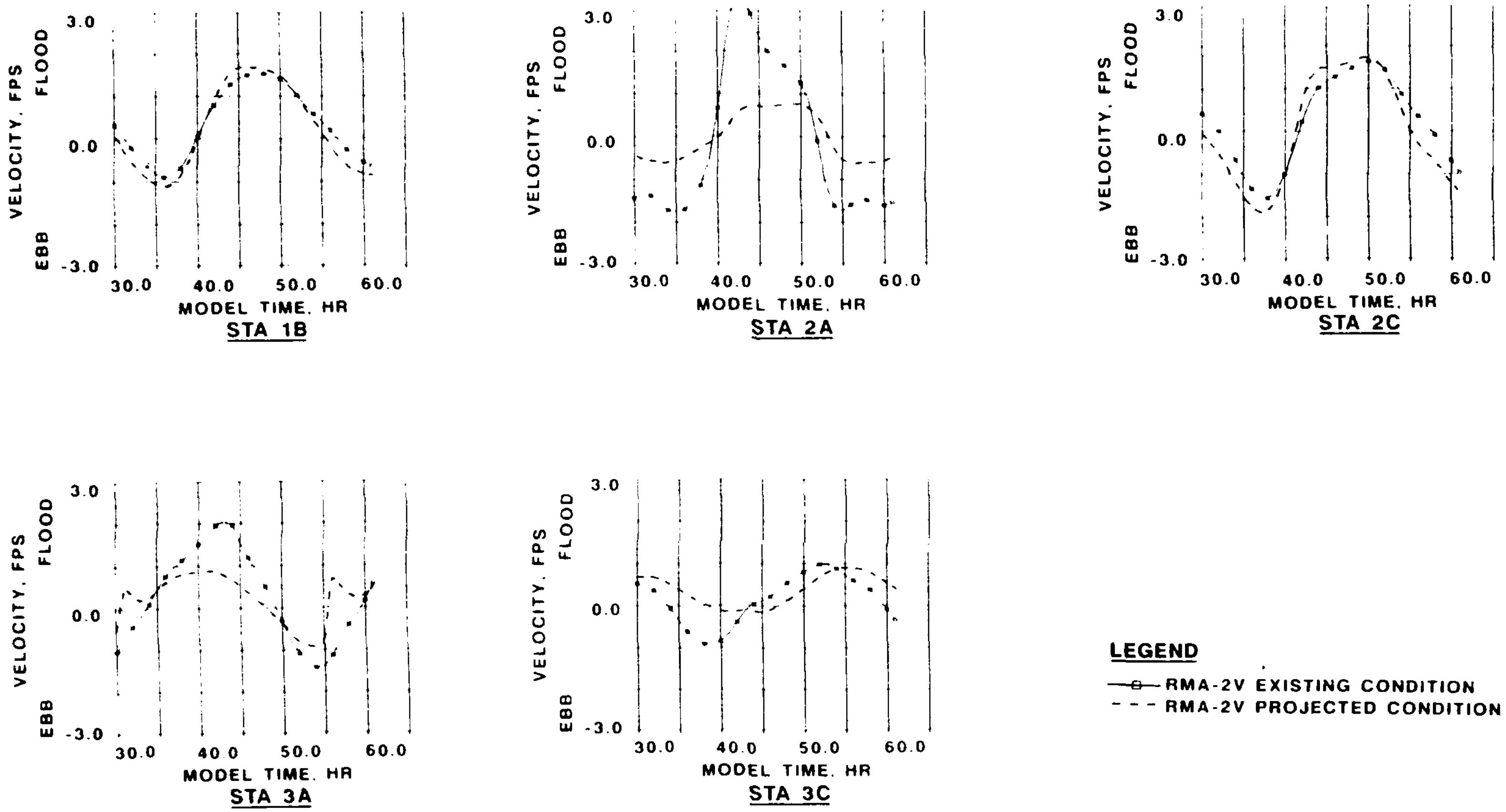
RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO 11-27-1988
TIDE STATIONS



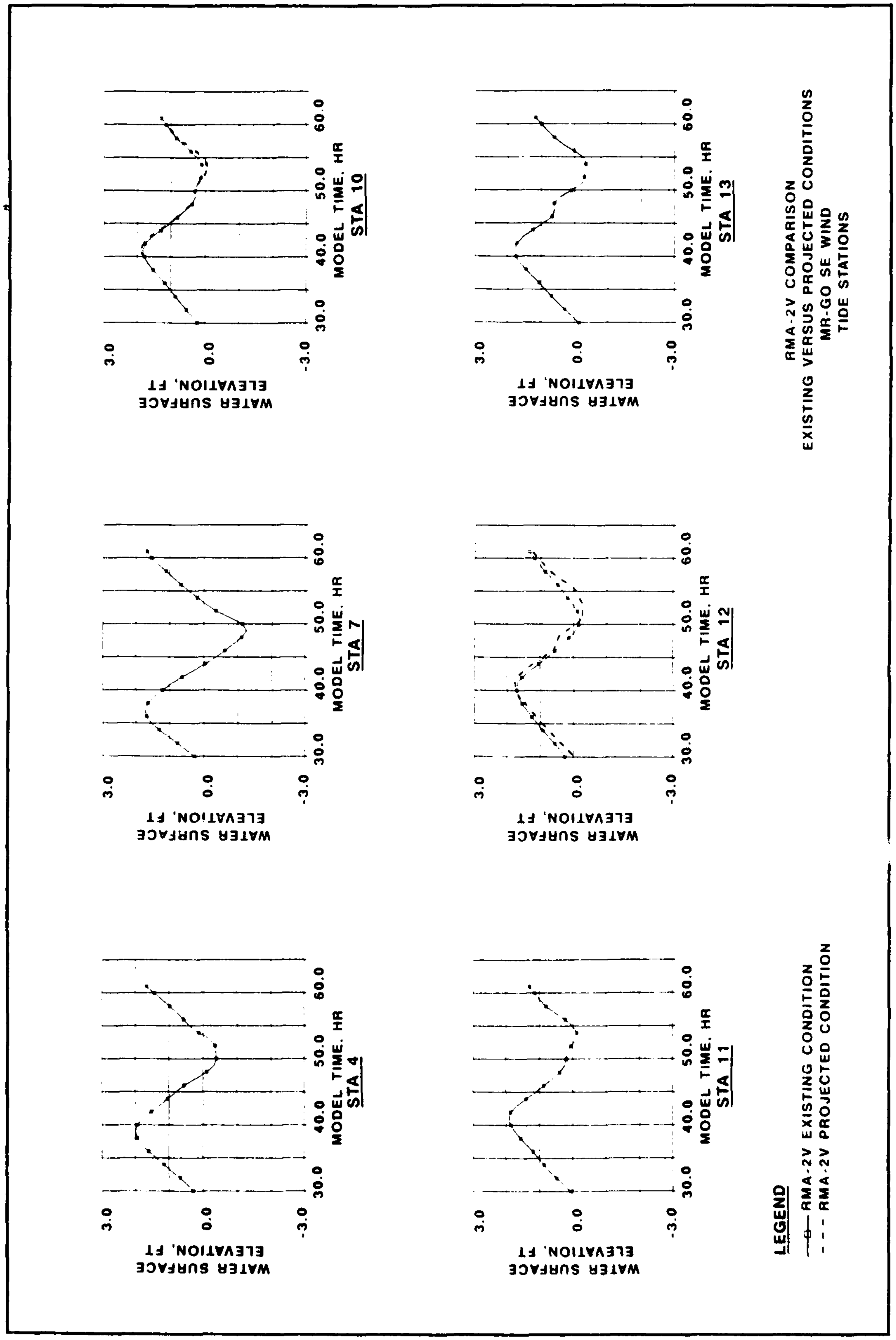
RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO 11-27-1988
VELOCITY STATIONS



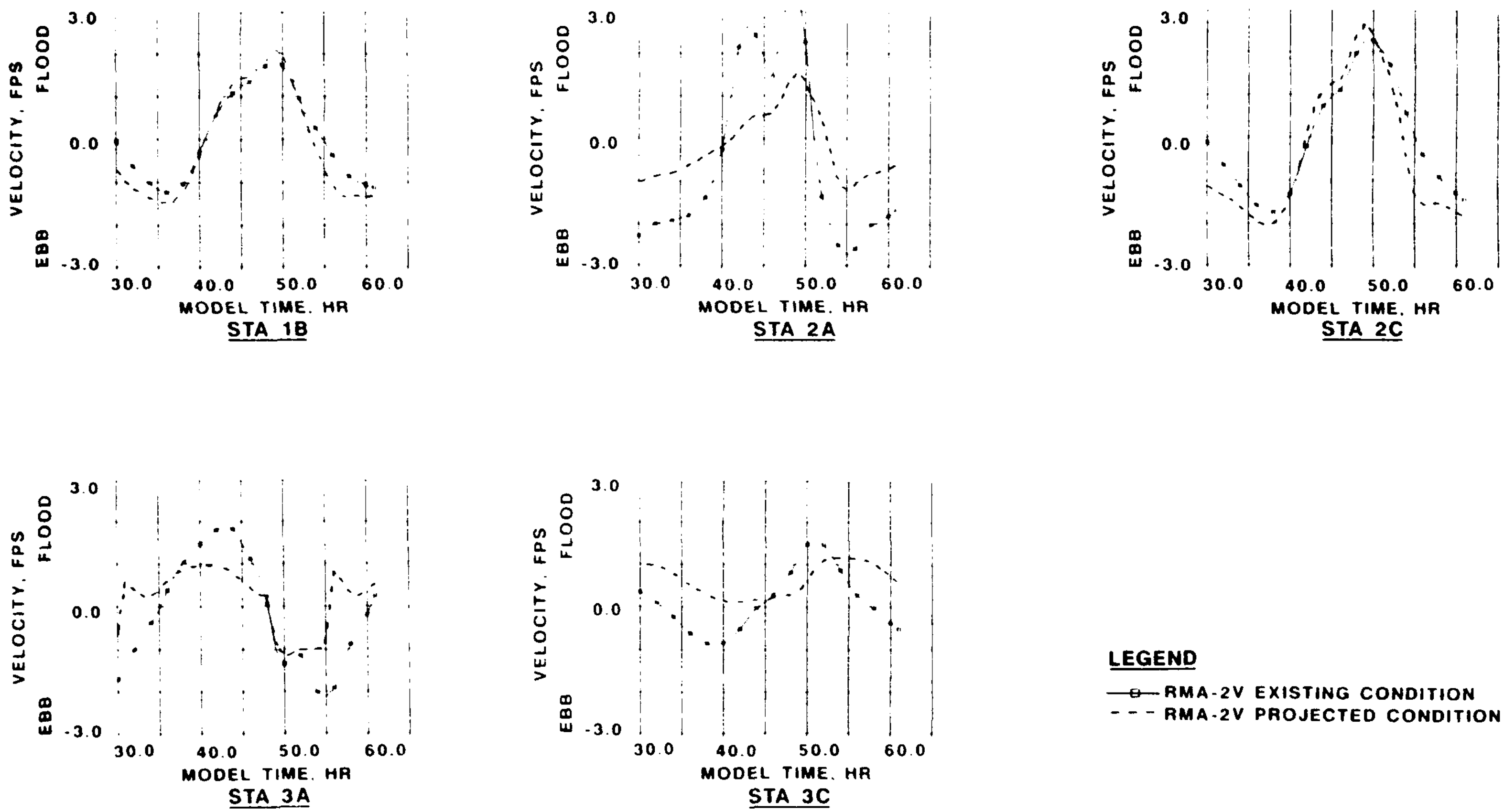
RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO E-NE WIND
TIDE STATIONS



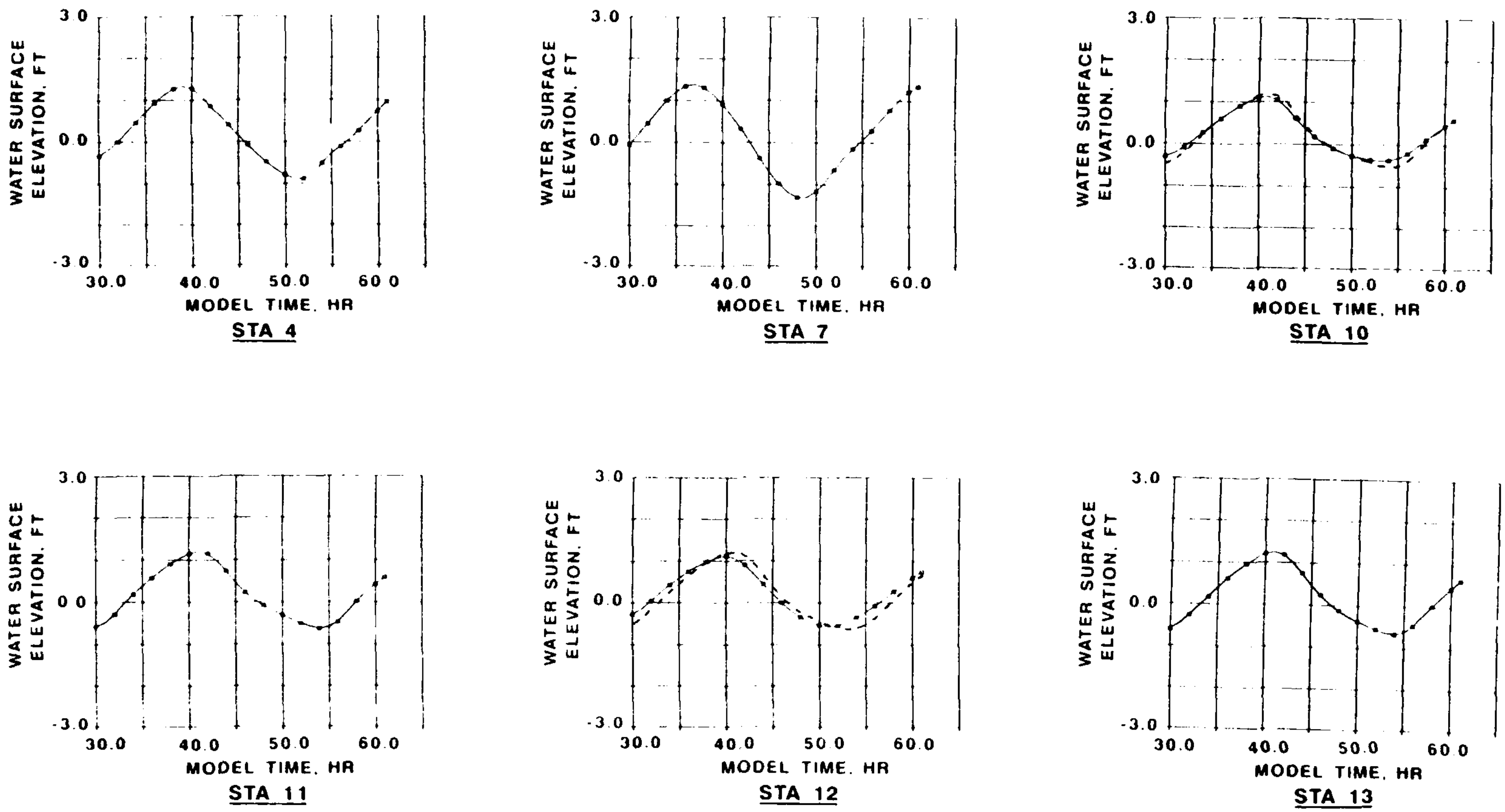
RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO E-NE WIND
VELOCITY STATIONS



RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO SE WIND
TIDE STATIONS



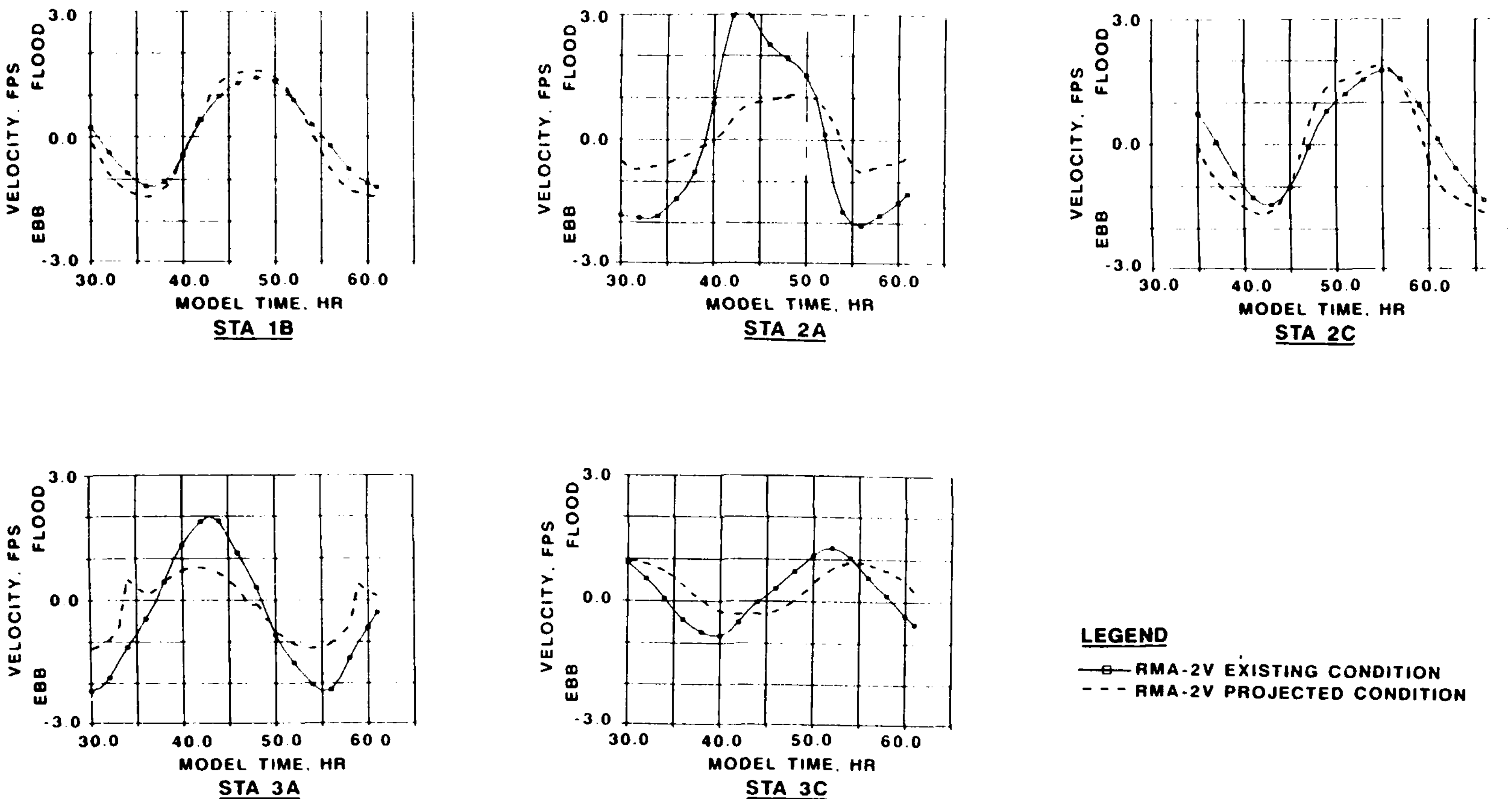
RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO SE WIND
VELOCITY STATIONS



LEGEND

- RMA-2V EXISTING CONDITION
- - - RMA-2V PROJECTED CONDITION

RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO NO WIND
TIDE STATIONS



RMA-2V COMPARISON
EXISTING VERSUS PROJECTED CONDITIONS
MR-GO NO WIND
VELOCITY STATIONS